

**COMPOSITE COUNTER-WEIGHT APPLICATION IN WASHING
MACHINE**

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ABBREVIATIONS

BaSO₄	: Barium Sulphate
CP	: Concrete Polymers
FRP	: Fibre Reinforced Plastics
GRP	: Glass Reinforced Plastics
MEKP	: Methyl Ethyl Ketone Peroxide
MMA	: Methyl Methacrylate
PC	: Polymer Concrete
PCC	: Polymer-Cement Concrete
PSC	: Polymer Sulphur Concrete
PMMA	: Polymethyl Methacrylate
TMPTMA	: Trimethylol Propane Methyl Methacrylate
UP	: Unsaturated Polyester

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LIST OF SYMBOLS

a	: length of the specimen
b	: width of specimen
E	: modulus of elasticity
E_y	: tensile strain
F	: applied load
h	: thickness of specimen
σ_c	: compression stress
x	: displacement

COMPOSITE COUNTER-WEIGHT APPLICATION IN WASHING MACHINES

SUMMARY

Dynamic systems of washing machines are balanced by the help of the concrete counter-weights. In Truva type washing machine (WM), designed by ARCELİK, two different counter-weights are used; one located at the top of the plastic tub and the other located in front of the WM. Polymer-composite materials are required by industry, as a result of their cost effectiveness and higher physical performance.

The aim of this thesis is, to design and manufacture composite material which will be applied as an alternative material to the counter-weight of the WM. Inhibition of physical and mechanical properties of the selected composites are also the goals of this work.

The first part of the thesis consists of a literature survey about the chemical composition, production methods and process technology of the polymer concrete. Three different methods to produce polymer concrete are obtained and Polymer Concrete (PC) is defined as the method of the study.

In the second part, experimental works were performed to evaluate the physical and mechanical properties of the composite specimens. The chemical components of the specimens were:

- Resin: Polyester in different ratio, varying from 20% to 30% (constant in all the specimens)
- Activators: Methyl Ethyl Ketone Peroxide and Cobalt-Naphtanate
- Fillers: Used die sand, unused die sand and BaSO₄ applied in different ratio, ranging from 70% to 80% (variable in all the specimens)

Nine different formulations which were prepared by the addition of polyester resin with different filler varying in both chemistry and amount. Three specimens for the same formulations were also prepared to be able to determine the effects of mixing and preparing errors. A special mould was designed and manufactured for casting the specimens. Finally, density measurement and compression tests were performed.

In the last part results of all the mechanical tests and density measurements were given and investigated in detail. Considering all the data gathered from these experiments, a suitable formulation among nine different formulations was chosen to be appropriate to be used in a composite counter-weight that would be exposed to washing machine working conditions. It was seen that polyester 25% - BaSO₄ 75% composites are the most appropriate material used in this work.

ÇAMAŞIR MAKİNALARI İÇİN KOMPOZİT DENGİ AĞIRLIĞI UYGULAMASI

ÖZET

Çamaşır makinelerinin tahrik grupları beton denge ağırlıkları vasıtasıyla dengelenmektedir. ARÇELİK tarafından tasarlanmış Truva tipi çamaşır makinelerinde, biri plastik kazanın üstünde, diğeri önünde olmak üzere iki farklı denge ağırlığı kullanılmaktadır. Fiyat avantajı ve yüksek fiziksel performansları nedeniyle kompozit malzemeler sanayide tercih edilmektedirler.

Bu tezin amacı çamaşır makinelerinde kullanılan denge ağırlığı için alternatif bir kompozit malzeme tasarlamaktır. Seçilen kompozitlerin fiziksel ve mekanik özelliklerin belirlenmesi de tezin amaçları arasındadır. Tezin ilk bölümü, polimer betonunun kimyasal yapısı, üretim metodları ve üretim teknolojisi hakkında literatür araştırmasını içermektedir. Polimer beton (PC) elde etmek için kullanılan üç farklı method mevcut olup; tez çalışması için polimer beton yöntemi seçilmiştir.

İkinci bölüm, malzemelerin fiziksel ve mekanik özelliklerin değerlendirilmesi için yapılan deneysel çalışmaları içermektedir. Numunelerin kimyasal bileşenleri şunlardır:

- Reçine: %20'den %30'a kadar değişen oranlarda Polyester (Reçine tüm numunelerde sabit alınmıştır.)
- Aktivatörler: Metil Etil Keton Peroksid and Kobalt-Naftanat
- Dolgular: 70'ten %80'e kadar değişen oranlarda uygulanmış olan kullanılmış kalıp kumu, kullanılmamış kalıp kumu ve BaSO₄ (Tüm numunelerde dolgu malzemesi değişken alınmıştır.)

Farklı kimyasal yapıda ve miktardaki dolgu malzemesi ile poliester reçinesi kullanılarak dokuz farklı formülasyon hazırlandı. Karışım oranları ve karıştırma esnasında oluşabilecek hataları göz önüne alabilmek için aynı formülasyondan üçer adet numune hazırlandı. Numuneleri dökülebilmek için özel bir kalıp tasarlanarak imal edildi. Son olarak, dökülen numunelere yoğunluk ölçümü ve basma testleri uygulandı.

Son bölümde yoğunluk ölçümleri ve basma testlerinin sonuçları elde edilerek düzenlendi ve detaylandırıldı. Deneylerden elde edilen tüm bulgular bir araya getirilerek dokuz farklı formülasyon arasından çamaşır makinesinin çalışma koşullarına maruz kalabilmeye en uygun olan seçildi. %25 poliester - %75 BaSO₄ kompozitinin çalışmadaki en uygun malzeme olduğuna karar verildi.

1. INTRODUCTION

In washing machines (WM) so as to suspend the unbalance especially in the higher spin speed values, concrete counter-weights are used. In Truva type plastic tubs designed by ARCELIK, which has maximum spin speed values between the range 1000 up to 1600 rpm two counter-weights are assembled, one at the top of the tub, one in front of the tub.

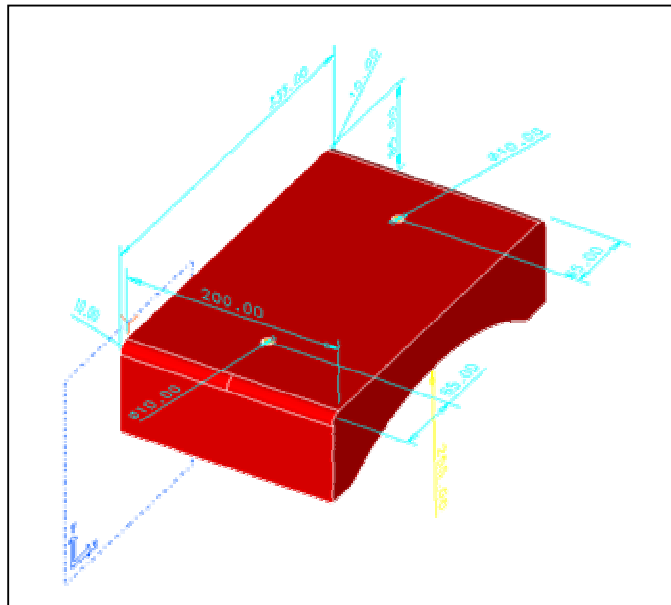


Figure 1.1 Top counter-weight of WM

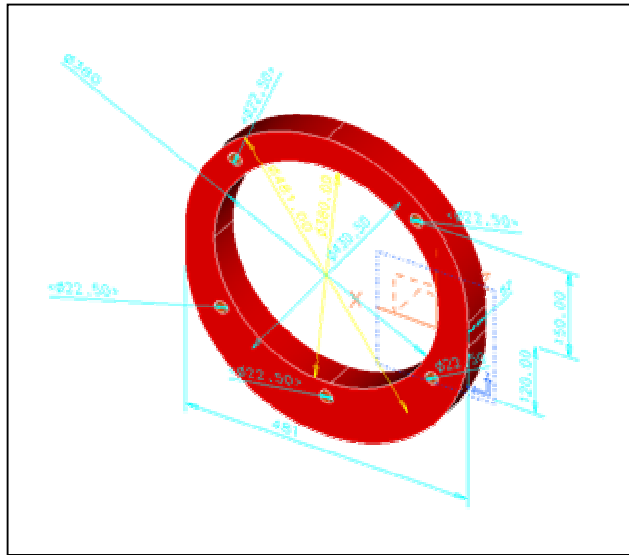


Figure 1.2 Front counter-weight of WM

Industry increasingly requires products that are cost effective and easy to use, with high physical performance. Incorporating a polymer in a cementitious mix brings key advantages, particularly in terms of workability, abrasion and impact resistance, with the resulting physical and chemical properties dependent upon the nature of the polymer material and the quantity used in relation to the cement phase.

The aim of this thesis is to apply composite counter-weight in washing machine. The first and second parts of the thesis consist of a literature survey about polymer concrete classification and composition. Three methods of producing polymer concrete is obtained according to the literature research and the appropriate method is chosen as polymer concrete of synthetic resin. Third part of the thesis deals with the investigation of three different filler and one constant resin in three different ratio of the mixture, and the experimental work including density measurement and mechanical testing. In the last part results of all the mechanical tests and density measurements are given and investigated in detail. Considering all the data gathered from these experiments, a suitable formulation among nine different formulations was chosen to be appropriate to be used in a composite matrix that would be exposed to conditions of the counter-weight.

2. THEORETICAL PART & LITERATURE SURVEY

2.1. Polymer Concrete

Polymer concretes represent a new generation of efficient and chemical-resistant materials in which the mineral fillers and aggregates reach 90 to 95% by weight. The content of the polymer binder in these comparatively new materials is only 5 to 10 % of the total weight of the polymer concrete. The cost of polymer concretes is therefore far less than that of plastics.

In spite of such a comparatively low consumption of polymer binder per unit weight, polymer concretes possess high density, strength, chemical resistance, and many other desirable features. The appropriate selection of binder, fillers and aggregates helps to produce polymer concretes with high dielectric characteristics or, on contrarily, those possessing good electrical conductivity, vacuum tightness, or damping characteristics. Compositions of special concretes with excellent properties of protection from various kinds of radiation have been developed. Further, the high proportion of fillers used in such concretes sharply reduces shrinkage (which is equal to that of cement concretes), while the modulus of elasticity is greatly enhanced. This permits the use of such concretes in load-bearing and other vital structural members and also in machine tool manufacturing and engineering industries. For example, compositions of polymer concretes having a density of 2200 to 2400 kg/m³ possess the following compressive strengths: based on phenol-formaldehyde resins 40-60 MPa, carbamide resins 50-80 MPa, polyester and methyl methacrylate resins 80-120 MPa, epoxide resins up to 150 MPa, vinyl esters and furan-epoxide resins up to 190 MPa.

Depending on the type of mineral fillers and aggregates, heat-insulating polymer concretes with a density ranging from 300-400 to 800-1000 kg/ m³, light polymer concretes with a density up to 1800-2000 kg/ m³ and super heavy polymer concretes with a density up to 5500 kg/ m³ can be produced.

The results of investigations show that the above physical and mechanical

characteristics of polymer concretes are not the maximum possible values and technological improvements can be expected to surpass these values significantly in the very near future. The great advances made in the chemical sciences and by the industry in the field of synthesizing new types of monomers and oligomers, many of which possess unique properties, point to such a possibility.

It is quite well known that one of the vital drawbacks of polymer concretes is their comparatively low thermal stability (80 to 120°C). Organosilicon and other binders which have already been developed can be used to produce polymer concretes with a thermal stability of up to 600°C or more.

Some ten types of monomers or oligomers are used throughout the world in various combinations along with modifiers to yield over thirty varieties of polymer concretes. The more extensively used are those based on polyesters and epoxide resins, vinyl esters and methyl methacrylate monomers. Phenol resins are used less frequently. Apart from these resins, polymer concretes based on furan, furan-epoxide, carbamide, and phenol-formaldehyde resins are also quite extensively used.

An analysis of the literature and the reports of international congresses on the use of polymers in concrete revealed a perceptibly increasing interest in these materials not only among specialists and scientists, but also a wide group of representatives from the industry. This is because the experience gained in using the various types of polymer concretes in extremely diverse fields has proved their positive features and cost effectiveness.

2.1.1. Classification of Polymer Concretes

The search for ways and means of increasing the strength, density, chemical resistance, and durability of plain and reinforced concrete has led to the formulation of a wide group of concretes with additives or based on polymers, called polymer concretes.

The use of polymers in concrete involves three fundamental principles: full or partial replacement of inorganic by organic aggregates; total or partial replacement of inorganic by organic binder; and introduction of organic binder into the porous structure of the cement, stone or concretes.

The substitution of inorganic by organic filler is directed towards obtaining light

concretes, reducing their average density, and improving their heat insulating characteristics. The properties of concrete using organic aggregates, for example, foam polystyrene, are practically no different from those which could be produced with inorganic aggregates, such as foam glass, claydite (day filler), azurite, etc.

A very complex picture emerges on the interaction of synthetic resins and cement used as binder, especially on totally replacing the inorganic by organic binder. In this case, material of a new type with special properties is formed.

It should be pointed out that, apart from a general classification, polymer concretes have also been classified according to the ease of application of the mixes, types of polymer binders and hardeners and degradation processes in polymer concretes under the influence of various aggressive media and physical effects.

According to the general classification developed by the authors, special concretes with additives or those based on polymers are divided into four main categories depending on the composition and the method of production: concretes based on polymer binders-polymer concretes (PC); cement concretes modified by polymers-polymer-cement concretes (PCC); sulphur concretes modified by polymers-polymer sulphur concretes (PSC); and cement concretes impregnated with monomers or oligomers-concrete polymers (CP) (Fig. 2.1).

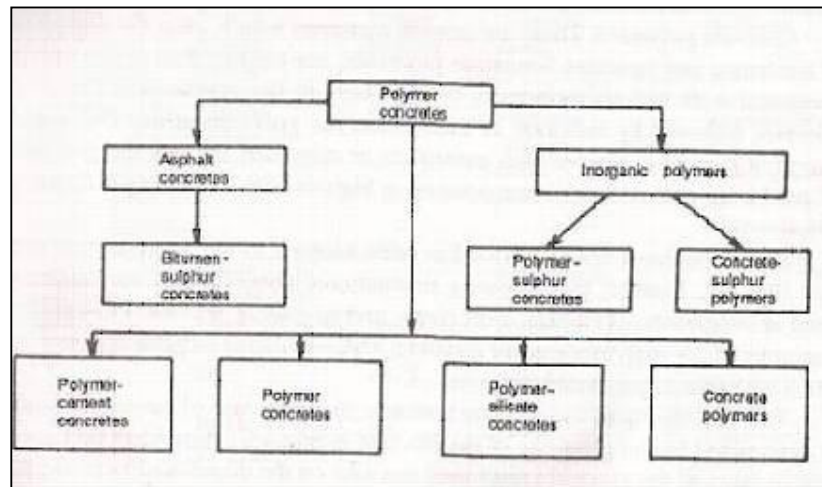


Figure 2.1 Classification of polymer concretes (Mikhailov, K.V., Paturoev, V.V., 1992)

Polymer concretes denote compositions based on synthetic resins or monomers and chemically stable fillers and aggregates without using mineral binders and water. The composition of polymer concretes consists of no less than three fractions of fillers and aggregates: finely dispersed fillers with a particle size less than 0,15 mm; aggregates-sand with a grain size up to 5 mm; and rubble up to 50 mm in size. Unlike polymer concretes, polymer slurries do not contain aggregates. Pastes contain only one dispersed filler fraction.

The main properties of polymer concretes are determined by the chemical nature of the synthetic resin and the type and content of the finely dispersed filler fraction. Coarse fractions of aggregates (sand and stone aggregates), while essentially performing the role of a skeleton, influence the main physical and mechanical properties to a small extent. Therefore, in the case of non-reinforced material, the abbreviation of the name of the polymer binder and the type of finely dispersed filler are shown after the word 'polymer concrete'; for reinforced material, the type of reinforcement is shown before the name of the material, e.g., polymer concrete FAM (grade of furan resin) based on andesite, polymer concrete PN (polyester maleinate resin) using marshalite (silica flour), steel polymer concrete FAM using agloporite, etc.

Polymer cement concretes (PCC) are cement concretes during the production of which organosilicon or water-soluble polymers, aqueous emulsions of the type of polyvinyl acetate, or water-soluble epoxide resins are added to the mix at 8-20%.

Polymer sulphur concretes (PSC) are concretes based on a sulphur binder during the production of which modifying additives of the type of dicyclopentadiene or chloroparaffin are added to the molten sulphur at 1-2 to 12-15%.

Concrete polymers (PC) are cement concretes which, after the completion of hardening and structure formation processes, are subjected to drying and impregnated with various monomers or oligomers in the porous structure of the concrete followed by radiation or thermo catalytic polymerization. The impregnation of the cement concrete with monomers or oligomers ensures the possibility of producing concrete polymers possessing high density and strength characteristics.

The workability of the polymer concrete, as in the ease of cement concretes, is

determined by the plasticity of the mix and is primarily dependent on the type and quantity of the synthetic resin used and also on the dispersability of the filler and the ratio between the fractions of the fillers and the aggregates. Polymer concrete mixes can be divided into four main groups based on their plasticity; their average compositions are given in Table 2.1. In this Table, the lower values of the quantity of resin refer to the heavy concretes and the higher values to the light concretes using porous aggregates.

Table 2.1 Classification of polymer concrete mixes based on workability
(Mikhailov, K.V., Paturoev, V.V., 1992)

*The amount of hardener is selected depending on consumption of the resin.

Material	Plasticity of polymer concrete mix depending on composition			
	Plastic	Normal	Stiff	Dry
Aggregates	51–52	53–55	56–57	58–60
Sand	23–24	25–26	25–27	27–28
Mineral flour	10–12	10–11	8–9	6–7
Synthetic resin	12–15*	9–12	6–8.5	5–6

The most important factor determining the properties of polymer concretes is the type of polymer binder and its compatibility and high adhesive bond with concretes based on inorganic binders. These are determined not only by the type of binder but also by the type of hardening system. For example, polymer concretes based on furan resins hardened by acidic catalysts should not be combined with cement concretes since, during hardening, the acid catalyst can damage the molecular structure of the cement concrete.

An analysis of the most common aggressive media and degradation processes noticed in polymer concrete structures showed that all external influences can be divided into two main groups based on the type of action on the polymer material. The first type includes the action of water and some other liquid media causing a reversible adsorptive reduction of strength; the second type includes the effects causing irreversible degradation processes.

In turn, the effects causing irreversible degradation or deterioration processes in polymer material can be divided into three main subgroups. The degradation is caused by the dissolution of the polymer by different solvents; accelerated formation of free radicals and atoms and chemical action with the aggressive products

associated with the deterioration of the polymer molecules.

The first subgroup represents the dissolution of the polymer binder by different solvents. For a binder based on thermosetting resins with a spatial cross-link, this type of action is manifest in limited ranges. There are highly active solvents for each type of binder.

For polymer concretes based on thermoplastic polymers, the intensity of the action of heat and various types of radiation can increase significantly; in such a case, the operational conditions and the types of permissible solvents acting on such polymer concretes should be more thoroughly studied.

The second subgroup combines the degradation processes associated with the action of heat and various types of radiation. It is known that sometimes the free radicals and atoms arising in the polymer under the action of heat, solar radiation, and radioactive radiations take active part in breaking down the polymers. Being reactive by nature, the free radicals and atoms break the polymer molecules and these fragments form new free radicals which also take part in the degradation process. As a result, the structure of the polymer, its chemical composition and molecular weight undergo change and, as a consequence, the physical and mechanical properties of the polymer also change.

Such degradation processes usually proceed most intensely in thermoplastic polymers with a linear structure. In this case, the breakdown of the polymers can be significantly inhibited by blocking the free radicals which arise initially as well as those formed as secondary products of the reactions. For these purposes, various stabilizers based on the derivatives of phenols, amines, sulphides, and organophosphorus compounds are added to the polymer at 0.1 to 3%.

The third subgroup represents the degradation of polymers associated with ionic and molecular processes which mostly occur under the influence of acids, oxidizing agents and alkalis.

Thus, by classifying the diverse reactive media and the external processes according to their typical effects and generalizing the results of laboratory investigations and the data of research on polymer concrete products and structures used in various industrial works and installations under the action of aggressive media, we can identify four main types of degradation of polymer concretes. Each type can be

defined by the sum total of prominent features.

All reversible processes arising in polymer concretes under the action of water and other non-aggressive liquids can be placed in the first type. As a result of liquid diffusion deep into the material, a weight increase and adsorptive reduction of strength arise. On drying, for instance, evaporation of the liquid from the material, the initial weight and strength are practically restored.

Processes which cause the dissolution of the polymer and its washout from the polymer concrete structure can be placed in the second type. In this process, there is a weight reduction of the material and also its strength reduction.

Degradation phenomena of the polymer binder associated with the appearance of free radicals and atoms can be placed in the third type. This type of destruction causes brittleness of the material and strength reduction. In this process, there is no perceptible weight variation of the material.

The fourth type of degradation of the polymer binder is associated with the breakdown of the polymer molecules under the action of acids, oxidizing agents and alkalis. The type of degradation causes an increase in weight, strength reduction and spilling of the material is given in Table 2.2.

Table 2.2 Classification of the process of degradation of polymer concretes
(Mikhailov, K.V., Paturoev, V.V., 1992)

Nature of action	Type of degradation	Degradation processes	Evaluation of degradation process	Factors controlling degradation kinetics
Physical processes (saturation with liquid non-aggressive media)	I	Adsorption and reduction of surface energy of solid body	Weight increase of material and strength reduction	Diffusion rate and stressed state
Physical and chemical processes (action of solvents)	II	Dissolution of polymer binder	Weight reduction of material and strength reduction	Diffusion rate and stressed state
Physical processes (action of temperature, solar radiation and radioactive radiation)	III	Physical and chemical degradation	Increase of brittleness and strength reduction	Intensity of action
Chemical reaction of aggressive media with polymer binder	IV	Acidic, oxidative, and alkaline degradations	Increase of material weight, appearance of cracks, and strength reduction	Rate of diffusion, concentration of aggressive medium, stressed state, and temperature

According to the hardener, the least favorable for the reinforcement in polymer concretes hardened by various acids. The third group of polymer concretes occupies an intermediate position with respect to these characteristics (Table 2.3).

Table 2.3 Classification of the polymer concretes according to type of hardener and stability of reinforcement (Mikhailov, K.V., Paturoev, V.V., 1992)

Hardener	Stability of reinforcement depending on type of fillers and aggregates			
	Acidic rocks (granites, etc.)	Neutral rocks (andesite etc.)	Porous	Carbon-graphite
Polymer concretes hardened by acids	Good	Good	Satisfactory	Unsatisfactory
Polymer concretes hardened by polyamines and alkalis	Good	Good	Good	Satisfactory
Polymer concretes hardened by peroxides	Good	Good	Good	Satisfactory

The reduction of intensity or the suppression of all types of degradation processes involves the correct selection of the polymer binder that is most stable under the action of actual aggressive media and achieving the maximum possible density of the polymer concretes so as to reduce the diffusive penetration of aggressive media deep into the material.

The classification of the types of polymer concrete degradation into the above four main types facilitates not only a more correct selection of the type of polymer concrete depending on the operational conditions and a more rational approach for formulating new polymer concrete compositions, but also helps to predict the behavior of the reinforcement in a given situation.

2.2. Polymer Modified Concrete

Polymer modified concrete may be divided into two classes: polymer impregnated concrete and polymer cement concrete. The first is produced by impregnation of precast hardened Portland cement concrete with a monomer that is subsequently converted to solid polymer. To produce the second, part of the cement binder of the concrete mix is replaced by polymer (often in latex form). Both have higher strength, lower water permeability, better resistance to chemicals, and greater freeze-thaw stability than conventional concrete.

Although its physical properties and relatively low cost make it the most widely used construction material, conventional Portland cement concrete has a number of limitations, such as low flexural strength, low failure strain, susceptibility to frost damage and low resistance to chemicals. These drawbacks are well recognized by the engineer and can usually be allowed for in most applications. In certain situations, these problems can be solved by using materials which contain an organic polymer or resin (commercial polymer) instead of or in conjunction with Portland cement. These relatively new materials offer the advantages of higher strength, improved durability, good resistance to corrosion, reduced water permeability and greater resistance to damage from freeze-thaw cycles.

There are three principal classes of composite materials containing polymers: polymer impregnated concrete; polymer cement concrete and polymer concrete. The distinction between these three classes is important to the design engineer in the

selection of the appropriate material for a given application.

The typical properties of these polymer-containing composites are compared with conventional Portland cement concrete in Table 2.4.

Table 2.4 Typical properties of polymer-containing concrete composites and portland cement concrete (**Blaga, A., Beaudoin, J. J., 1985**).

Material	Tensile Strength, Mpa	Modulus of Elasticity, Gpa	Compressive Strength, Mpa	Shear Bond Strength, Kpa	Water Sorption, %	Freeze-thaw Resistance, No. Of Cycles / % Wt. Loss	Acid Resistance
Polymer impregnated concrete	10,5	42	140	-	0,6	3500/2	10
Polymer impregnated concrete	14,7	49	273	-	≤0,6	-	≥10
Polymer Cement Concrete	5,6	14	38	≥4,55	-	-	4
Portland Cement Concrete	2,5	24,5	35	875	5,5	700/25	-

2.2.1. Polymer Impregnated Concrete

Polymer impregnated concrete is made by impregnation of precast hardened Portland cement concrete with low viscosity monomers (in either liquid or gaseous form) that are converted to solid polymer under the influence of physical agents (ultraviolet

radiation or heat) or chemical agents (catalysts). It is produced by drying conventional concrete; displacing the air from the open pores (by vacuum or monomer displacement and pressure); saturating the open pore structure by diffusion of low viscosity monomers or a prepolymer-monomer mixture (viscosity 10 cps; 1×10^{-2} Pa*s); and polymerization of the monomer or prepolymer-monomer mixture, using the most economical and convenient method (radiation, heat or chemical initiation). The important feature of this material is that a large proportion of the void volume is filled with polymer, which forms a continuous reinforcing network. The concrete structure may be impregnated to varying depths or in the surface layer only, depending on whether increased strength and/or durability is sought. The main disadvantages of polymer impregnated concrete products are their relatively high cost, as the monomers used in impregnation are expensive and the fabrication process is more complicated than for unmodified concrete.

Impregnation of concrete results in a remarkable improvement in tensile, compressive and impact strength enhanced durability and reduced permeability to water and aqueous salt solutions such as sulfates and chlorides. The compressive strength can be increased from 35 MPa to 140 MPa, the water sorption can be reduced significantly and the freeze-thaw resistance is considerably enhanced. The greatest strength can be achieved by impregnation of autoclaved concrete. This material can have a compressive-strength-to-density ratio nearly three times that of steel. Although its modulus of elasticity is only moderately greater than that of non-autoclaved polymer impregnated concrete, the maximum strain at break is significantly higher.

The monomers most widely used in the impregnation of concrete are the vinyl type, such as methyl methacrylate (MMA), styrene, acrylonitrile, t-butyl styrene and vinyl acetate. Acrylic monomer systems such as methyl methacrylate or its mixtures with acrylonitrile are the preferred impregnating materials, because they have low viscosity, good wetting properties, high reactivity, relatively low cost and result in products with superior properties. By using appropriate bifunctional or polyfunctional monomers (cross-linking agents) in conjunction with MMA, a cross-linked network is formed within the pores, resulting in products with greatly increased mechanical strength and higher thermal and chemical resistance. Improvement of these properties will depend on the degree of cross-linking. A cross-

linking agent commonly used with vinyl monomers such as MMA and styrene is trimethylolpropane trimethacrylate.

Thermosetting monomers and prepolymers are also used to produce polymer impregnated concrete with greatly increased thermal stability (i.e. resistance to deterioration by heat). These include epoxy prepolymers and unsaturated polyester-styrene. These monomers and prepolymers are relatively viscous and, therefore, their use results in reduced impregnation. Their viscosity can be reduced by mixing them with low-viscosity monomers such as MMA.

2.2.2. Polymer Cement Concrete

Polymer cement concrete is a modified concrete in which part (10 to 15% by weight) of the cement binder is replaced by a synthetic organic polymer. It is produced by incorporating a monomer, prepolymer-monomer mixture, or a dispersed polymer (latex) into a cement-concrete mix. To effect the polymerization of the monomer or prepolymer-monomer, a catalyst is added to the mixture. The process technology used is very similar to that of conventional concrete. Therefore, polymer cement concrete can be cast-in-place in field applications, whereas polymer impregnated concrete has to be used as a precast structure.

The properties of polymer cement concrete produced by modifying concrete with various polymers range from poor to quite favorable. Poor properties of certain products have been attributed to the incompatibility of most organic polymers and monomers with some of the concrete mix ingredients. Better properties are produced by using prepolymers, such as unsaturated polyester cross-linked with styrene or epoxies. To achieve a substantial improvement over unmodified concrete, fairly large proportions of these polymers are required. The improvement does not always justify the additional cost.

Modification of concrete with a polymer latex (colloidal dispersion of polymer particles in water) results in greatly improved properties, at a reasonable cost. Therefore, a great variety of latexes is now available for use in polymer cement concrete products and mortars. The most common latexes are based on poly (methyl methacrylate) also called acrylic latex, poly (vinyl acetate), vinyl chloride copolymers, poly (vinylidene chloride), (styrene-butadiene) copolymer, nitrile rubber and natural rubber. Each polymer produces characteristic physical properties. The

acrylic latex provides a very good water-resistant bond between the modifying polymer and the concrete components, whereas use of latexes of styrene-based polymers results in a high compressive strength.

Curing of latex polymer cement concrete is different from that of conventional concrete because the polymer forms a film on the surface of the product retaining some of the internal moisture needed for continuous cement hydration. Because of the film-forming feature, moist curing of the latex product is generally shorter than for conventional concrete.

Generally, polymer cement concrete made with polymer latex exhibits excellent bonding to steel reinforcement and to old concrete good ductility resistance to penetration of water and aqueous salt solutions, and resistance to freeze-thaw damage. Its flexural strength and toughness are usually higher than those of unmodified concrete. The modulus of elasticity may or may not be higher than that of unmodified concrete, depending on the polymer latex used. For instance, the more rubbery the polymer is, the lower the modulus. Generally, as the polymer forms a low modulus phase with the polymer cement concrete, the creep is higher than that of plain concrete and decreases with the type of polymer latex used in the following order: polyacrylate; styrene-butadiene copolymer; polyvinylidene chloride; unmodified cement.

The drying shrinkage of polymer cement concrete is generally lower than that of conventional concrete; the amount of shrinkage depends on the water-to-cement ratio, cement content, polymer content and curing conditions. It is more susceptible to higher temperatures than ordinary cement concrete. For example, creep increases with temperature to a greater extent than in ordinary cement concrete, whereas flexural strength, flexural modulus and modulus of elasticity decrease. These effects are greater in materials made with elastomeric latex (e.g., styrene-butadiene rubber) than in those made with thermoplastic polymers (e.g., acrylic). Typically, at about 45°C, polymer cement concrete made with thermoplastic latex retains only approximately 50 percent of its flexural strength and modulus of elasticity.

Polymer mortar and concrete are the composite materials made by fully replacing the cement hydrate binders of conventional mortar and concrete with polymeric binders or liquid resins such as thermosetting resins, vinyl monomers, and tar-modified

resins. They do not contain a cement hydrate phase. Most of the thermosetting resin and monomer systems for the polymer mortar and concrete are polymerized at ambient or room temperature.

The early development of polymer mortar and concrete was done mainly in the Soviet Union, the U.S., Germany, and Japan in the late 1950s to the early 1960s.

2.3. Polymer Concrete

PC is a composite material in which the binder consists entirely of a synthetic organic polymer. It is variously known as synthetic resin concrete, plastic resin concrete or simply resin concrete. Because the use of a polymer instead of Portland cement represents a substantial increase in cost, polymers should be used only in applications in which the higher cost can be justified by superior properties, low labor cost or low energy requirements during processing and handling. It is therefore important that architects and engineers have some knowledge of the capabilities and limitations of PC materials in order to select the most appropriate and economic product for a specific application.

2.3.1. Principle of Polymer Replacement

In polymer mortar and concrete, the cement hydrate binders of conventional mortar and concrete are replaced with polymeric binders, and the aggregates are strongly bound to each other by the uniform polymer matrix phases obtained from the polymeric binders. Accordingly, in comparison with ordinary cement mortar and concrete, the properties such as strength, adhesion, water tightness, chemical resistance, freeze-thaw durability, and abrasion resistance of the polymer mortar and concrete are generally improved to a great extent by polymer replacement. On the other hand, their poor thermal and fire resistance and their large temperature dependence of mechanical properties are disadvantages due to the undesirable properties of the polymer matrix phases. Therefore, the glass transition point (or temperature) of the polymer matrix phases should be noted from the viewpoint of such thermal properties. Thermoplastic resins generally retain their practical properties at temperatures below the glass transition point and lose them at temperatures exceeding the point, beginning to thermally decompose at somewhat higher temperatures. The practical temperature range of the thermoplastic resins may

be improved by the addition of suitable cross-linking monomers or comonomers having higher glass transition points. Thermosetting resins do not commonly show a glass transition point, and they retain their mechanical properties up to the thermal decomposition temperature. Such essential disadvantages of the polymer mortar and concrete can be considerably improved by controlling the necessary polymeric binder content by volume to a minimum.

Except for their special applications, when continuous polymer matrix phases in polymer mortar and concrete are formed by using sufficient polymeric binders, the polymer mortar and concrete with good properties can be produced. When the polymer matrix phases are discontinuous because of too small polymeric binder content or excessive entraining air content, their properties tend to become inferior.

The cost of various polymers for the polymeric binders is quite high compared to that of Portland cement or other cements. Consequently, it is most important for their mix design to find out the necessary minimal contents of the polymeric binders to disperse the aggregates in close-packed conditions in the continuous polymer matrix phases. The bond or adhesion between the polymeric binders and aggregates in the polymer mortar and concrete is very strong, differing from that between the cement hydrate binders and aggregates in the ordinary cement mortar and concrete. As a result, the strength properties of the polymer mortar and concrete tend to depend on the polymeric binder-aggregate bond or adhesion. Accordingly, the use of high-strength aggregates is required in their structural applications. Also, it is necessary to devise proper mixing procedures to reduce the entrained air content of the polymer mortar and concrete, as the use of the usual antifoaming agents is impossible.

2.3.2. Nature and General Properties of Polymer Concrete

Polymer concrete consists of a mineral filler (for example, an aggregate) and a polymer binder (which may be a thermoplastic, but more frequently, it is a thermosetting polymer. When sand is used as filler, the composite is referred to as a polymer mortar. Other fillers include crushed stone, gravel, limestone, chalk, condensed silica fume (silica flour, silica dust), granite, quartz, clay, expanded glass, and metallic fillers. Generally, any dry, non-absorbent, solid material can be used as filler.

To produce PC, a monomer or a prepolymer (i.e., a product resulting from the

partial polymerization of a monomer), a hardener (cross-linking agent) and a catalyst are mixed with the filler. Other ingredients added to the mix include plasticizers and fire retardants. Sometimes, silane coupling agents are used to increase the bond strength between the polymer matrix and the filler. To achieve the full potential of polymer concrete products for certain applications, various fibre reinforcements are used. These include glass fibre, glass fibre-based mats, fabrics and metal fibres. Setting times and times for development of maximum strength can be readily varied from a few minutes to several hours by adjusting the temperature and the catalyst system. The amount of polymer binder used is generally small and is usually determined by the size of the filler. Normally the polymer content will range from 5 to 15 percent of the total weight, but if the filler is fine, up to 30 percent may be required.

Polymer concrete composites have generally good resistance to attack by chemicals and other corrosive agents; have very low water sorption properties, good resistance to abrasion and marked freeze-thaw stability. Also, the greater strength of polymer concrete in comparison to Portland cement concrete permits the use of up to 50 percent less material. This puts polymer concrete on a competitive basis with cement concrete in certain special applications. The chemical resistance and physical properties are generally determined by the nature of the polymer binder to a greater extent than by the type and the amount of filler. In turn, the properties of the matrix polymer are highly dependent on time and the temperature to which it is exposed.

The viscoelastic properties of the polymer binder give rise to high creep values. This is a factor in the restricted use of PC in structural applications. Its deformation response is highly variable depending on formulation; the elastic module may range from 20 to about 50 GPa, the tensile failure strain being usually 1%. Shrinkage strains vary with the polymer used (high for polyester and low for epoxy-based binder) and must be taken into account in an application.

A wide variety of monomers and prepolymers are used to produce PC. The polymers most frequently used are based on four types of monomers or prepolymer systems: MMA, polyester prepolymer-styrene, epoxide prepolymer hardener (cross-linking monomer) and furfural alcohol. The typical range of properties of PC products made with each of these four polymers is presented in Table 2.5 and general characteristics

and principal applications are described in Table 2.6.

Table 2.5 Typical Range of Properties of Common PC Products and Portlan Cement Concrete (Blaga, A., Beaudoin, J. J., 1985)

Type of Binder	Density kg/dm	Water Sorption %	Compressive Strength MPa	Tensile Strength MPa	Flexural Strength MPa	Modulus of Elasticity GPa	Poisson Ratio	Thermal Coefficient of Expansion 10^6C^{-1}
Poly (methylmet hacrylate)	2.0-2.4	0.05-0.60	70-210	9-11	30-35	35-40	0.22-0.33	10-19
Polyester	2.0-2.4	0.30-1.0	50-150	8-25	15-45	20-40	0.16-0.30	10-30
Epoxy	2.0-2.4	0.02-1.0	50-150	8-25	15-50	20-40	0.30	10-35
Furan polymer	1.6-1.7	0.20	48-64	7-8	-	-	-	38-61
Portland cement Concrete**	1.9-2.5	5-8	13-35	1.5-3.5	2-8	20-30	0.15-0.20	10-12

Table 2.6 General Characteristics and Applications of Polymer Concrete Products
(Blaga, A., Beaudoin, J. J., 1985)

Type of Binder Used in PC	General Characteristics
Poly(methylmethacrylate)	Low tendency to absorb water; thus high freeze-thaw resistance; low rate of shrinkage during and after setting; very good chemical resistance and outdoor durability.
Polyester	Relatively strong, good adhesion to other materials, good chemical and freeze-thaw resistance, but have high-setting and post-setting shrinkage.
Epoxy	Strong adhesion to most building materials; low shrinkage; superior chemical resistance; good creep and fatigue resistance; low water sorption.
Furan-based polymer	Composite materials with high resistance to chemicals (most acidic or basic aqueous media), strong resistance to polar organic liquids such as ketones, aromatic hydrocarbons, and chlorinated compounds.

2.3.3. Types of Polymer Concrete According to the Resin

2.3.3.1. Acrylic Polymer Concrete

The most common acrylic polymer is poly (methyl methacrylate) (PMMA), obtained by polymerization of MMA. PC made with this acrylic polymer as a binder is a

versatile material, has excellent weathering resistance, good waterproofing properties, good chemical resistance, and relatively low setting shrinkage (0.01 to 0.1%); its coefficient of thermal expansion is equivalent to that of Portland cement concrete. Because of its very low tendency to absorb water, acrylic PC has a very high freeze-thaw resistance. The low flash point (11°C) of the MMA monomer is a disadvantage, however as it constitutes a safety problem.

Although the MMA monomer is more expensive than the prepolymer-monomer used in the more popular polyester PC, its unique properties account for its use in a great many diverse applications, including the manufacture of stair units, sanitary products, curbstones, and facade plates. A highly successful development has been its use as a rapid-setting, structural patching material for repairing large holes in bridge decks. The material consists of a highway grade aggregate and a matrix produced by cross-linking MMA with trimethylol propane trimethacrylate (TMPTMA).

2.3.3.2. Polyester Polymer Concrete

Because of low cost, the most widely used polymer-binders are based on unsaturated polyester polymer. In most applications, the polyester binder is a general purpose, unsaturated polyester prepolymer formulation. These formulations are available in the form of 60 to 80 percent solutions of the prepolymer in copolymerizable monomers such as styrene and styrene-methyl methacrylate. During hardening, the polyester prepolymer and the monomer react through their unsaturated groups (double bonds). The chemical reaction is called cross-linking, the production process associated with it is referred to as curing, and the resulting polymer binder is a thermosetting polymer.

Polyester PC has good mechanical strength, relatively good adhesion to other materials, and good chemical and freeze-thaw resistance. It has, however large setting and post-setting shrinkage (up to ten times greater than Portland cement concrete), a serious disadvantage in certain applications. Polyester PC is used in various precast and cast-in place applications in construction works.

2.3.3.3. Epoxy Polymer Concrete

Epoxy binder like polyester, is a thermosetting polymer The epoxy polymer can be

hardened with a variety of curing agents, the most frequently used being polyamines (e.g., tertiary polyamines). The use of polyamine hardeners (curing agents) results in PC products with the highest chemical resistance. Other curing agents are polyamides and polysulfide polymers. Epoxy PC products cured with polyamides have greater flexibility, better heat resistance, and reduced chalking tendency in outdoor exposure, but their solvent and chemical resistance is lower than for similar products cured with polyamines. The polysulfide polymers usage produce epoxy PC with even greater flexibility.

Epoxy PC exhibits high strength adhesion to most materials, low-setting and post-setting shrinkage, high chemical resistance, and good fatigue and creep resistance. Because they are relatively expensive, epoxy polymers have not been used very widely as binders in PC products. Therefore, epoxy PC is used for special applications, in situations in which the higher cost can easily be justified, such as mortar for industrial flooring to provide physical and chemical resistance, skid-resistant overlays (filled with sand, emery, pumice, quartz) in highways, epoxy plaster for exterior walls (e.g., in exposed aggregate panels) and resurfacing material for deteriorated areas (e.g., in flooring). Epoxy PC reinforced with glass, carbon or boron fibres is used in the fabrication of translucent panels, boat hulls and automobile bodies.

2.3.3.4. Furan Polymer Concrete

Furan polymers are based on furfuryl alcohol, which is derived from agricultural residues such as corn cobs, rice hulls, oat hulls or sugar cane bagasse. The furan prepolymer is usually cross-linked with furfuryl alcohol, furfuraldehyde or formaldehyde to yield thermosetting polymers, highly resistant to most aqueous acidic or basic solutions and strong solvents such as ketones, aromatics, and chlorinated compounds. The furan polymers are used as binders in mortars and grouts to achieve chemically resistant brick floors (e.g., carbon brick and red shale brick) and linings. In addition to exhibiting superior chemical resistance, these floors have excellent resistance to elevated temperatures and extreme thermal shock.

2.4. Process Technology of Polymer Concrete

Process technology of polymer mortar and concrete is much the same as that of

conventional cement mortar and concrete are basically applicable, but the curing methods differ. The batching, mixing, and placing techniques for cement mortar and concrete are basically applicable, but the curing methods differ. The optimum cures, such as dry cure at ambient temperature or heat cure, are selected and applied to the polymer mortar and concrete. In general, the process technology of the polymer mortar and concrete is divided into two types: cast-in-place and precast application systems. At present, the cast-inplace application systems are chiefly applied for the polymer mortar, and the precast application systems are used for the polymer concrete. For purposes of reducing the cost of the polymer mortar and concrete and improving their strength, durability, and other properties, it is most important to find out the effective mix proportions of the polymeric binders and aggregates. Although the polymeric binders are toxic and flammable, the use of the safety procedures that have been well established for them allows them to be handled without undue difficulty.

2.4.1. Specifications for Process Equipment for Producing Polymer Concrete Products and Structures

The production method is not the least of the factors that determine the properties of polymer concretes. The problem of producing high-quality materials possessing optimum characteristics calls for optimum methods of their production.

Two essentially different methods of producing polymer concretes are recognized:

- batch method
- continuous methods

Both methods have distinct advantages depending on the objectives set out, requirements skills of workers, planned production indexes, and so forth.

The main link in any technological flow sheet determining in particular the technological process and the period required for producing the materials and products is the mixer unit in which the polymer concrete mix is produced. Various constituents of the reaction are mixed in the mixer and the process once initiated cannot thereafter be stopped. It is therefore essential to select a proper mixing device.

The selection of mixing technology is independent of the method of producing the

polymer concretes. The following are the requirements for the mixing devices.

The mixing unit should thoroughly blend all the individual constituents to yield a homogeneous mass. All the fractions of the filler should be adequately wetted by the binder and the formation of lumps or the presence of dry patches in the mix is not permissible. The dispersed fibre reinforcement, when additionally added to the mix, should be distributed uniformly throughout the mass and also wetted well. The unit should be fast working. The hardening process commences when the constituents of the mix come into direct contact with each other. The time available before hardening of the mass should be utilized for thorough mixing of the constituents to a state of a homogeneous polymer concrete mass, compaction and complete processing into the finished product. Any loss of time in the mixer affects the entire time sequence. It should also be remembered that a chemical reaction occurs in the mixer; the mixer should be cleaned at the appropriate time therefore.

Stratification of the filler is not permissible. This is particularly important when materials of different densities such as quartz sand and hollow glass globules are used in the mixture of fillers. Breakage of the filler granules is not permissible, yet is entirely possible when using light aggregates.

The mixer unit should be amenable to rapid and easy cleaning. The remains of the polymer concrete mass in the mixer and the requirement of detergents and other cleaning (washing) agents should be low while the amount of chemical solvents used for cleaning should be optimal. Simplicity and ease of cleaning also ensure the economy of wages of the operators.

The mixer device should satisfy all the requirements of production capacity. For example, when producing castings weighing 5 tones, 50-litre batch mixers should not be used since a hundred mixing cycles one after another will then have to be performed. It should also be borne in mind that the unit should not produce more polymer concrete than can be processed in a given time interval. The mixer unit should satisfy the requirements of environmental protection. For example, some systems of binders call for the use of explosion-proof equipment. Sometimes, the mixer unit is coupled with other processing machinery. Climatic conditions, particularly when working directly at the construction site, exert a definite influence.

Batch mixers are most suitable for producing test batches and a small number of

products. The following types of batch mixers are used:

- Buckets (1,2,3 liter capacity) and agitators, these represent cheap tools which are wholly suitable for initial tests and for producing prototypes of articles;
- Paddle mixers, apart from being very slow in operation, are difficult to clean. These devices are not suitable when using brittle fillers, due to the generation of intense shearing forces, but are relatively cheap;
- Stirrers with oscillating paddles are also very slow in operation and mixing efficiency is not very high, but shearing forces are low;
- Propeller agitators are used primarily in the food and aniline dye industries. The operation of these mixers is extremely rapid but there is danger of break-up of brittle fillers by the rapidly rotating paddles in these mixers. However, the paddles may themselves be damaged by the action of coarse fillers and may become prematurely worn out. Expenses on repair of these mixers are therefore high;
- Truck-mounted concrete mixers are used for producing polymer concrete, especially when The volume of material required is large as, for example, when lining finished embankments. Inaccuracies of dosing the reaction constituents and also lack of adequate supervision by the personnel often lead to the hardening of the polymer concrete solution in the mixer. Thus situations have arisen wherein the hardened polymer concrete slurry and the mixer itself could not be utilized;
- Integrated mixers function rapidly, can be easily cleaned, and do not use paddles or blades. Thus these mixers preserve the fillers in good condition for a long time.

However, all batch mixers suffer from deficiencies which are particularly distinctly manifest when producing polymer concrete. After each process of mixing, they have invariably to be thoroughly cleaned. Moreover, the remains of the materials and solvents after each cleaning have to be removed, which does not always conform to the principles of environmental protection. Binders are used not only for wetting the fillers, but are also needlessly used for wetting the mixing drum, paddles, and so forth. Therefore, each operation of the mixer requires expensive binders in a larger

volume than is required in the composition of a given mix.

Irrespective of the rate of operation of the batch mixers, polymer concrete requires considerable duration for hardening and work cannot be performed on a continuous basis. This is because hardening begins only on completion of the processing of the entire batch of the mix present in the mixer and then the equipment requires cleaning. Therefore, when working with mixers having low hardening periods, batch mixers are unsuitable. In such cases, it is necessary to use continuous mixers which, at present, are already being used for producing cement-based concretes since; in this case also, there is rapid hardening of the mixes as a result of using chemical additives with the cement.

The batch method of mixing calls for periodic dosing of all the individual constituents of polymer concretes. Most often, dosing is manual and hence accuracy and uniformity of dosing depends on the experience of the personnel. Errors in dosing do arise from time to time but they are detected far too late to take any corrective measure. Therefore, in plants operating on a batch system, hardening often occurs either very late or not at all. Often, the reaction commences at the moment when the mix is right in the mixer itself.

Continuous production of polymer concrete products using batch mixers is practically impossible. Continuously working dosers, mixers, and casting equipment meet the requirements of large-scale production as also for producing special products against special orders. These machines are used not only as mixers, but are also capable of ensuring continuous and accurate dosing of all types of raw materials required for producing polymer concrete slurries so that all the technological operations, i.e., dosing, mixing and casting the products, can be combined into a single technological process. This eliminates time losses and ensures high accuracy and uniform operation.

A vital deficiency of casting machines compared with batch mixers is that they involve very high capital investment which, however, is compensated by several advantages:

- The individual constituents of the mix are dosed mechanically and uniformly; the selected individual constituents of the mix are added continuously with no deviation from the prescribed feeding procedure; human error is eliminated

and the machine yields a homogeneous polymer slurry all through the technological process;

- All the dosages of the various constituents of the mix can be regulated, each composition can be easily reproduced and repeated; even the reproduction of a precise colour shade is possible as, for example, to match with polymer marble or polymer onyx after a long interval;
- Within the framework of the technological process, all the operations can be carried out at strictly defined time intervals, the latter being maintained very accurately irrespective of changes in climatic conditions, which exert a definite influence on the course of the reaction;
- The optimum properties of polymer concretes are possible only when the hardening is of high quality; casting machines with a high rate of mixing help to ensure rapid hardening of the mixes resulting in thorough polymerisation of the polymer concrete and in many cases eliminating the need for thermal processing;
- Continuous production considerably enhances the economic efficiency of producing finished products while the use of casting machines helps considerably in reducing the number of workers;
- As long as the casting machine functions in a continuous regime, there is no need to clean it. It is subjected to cleaning only in the case of a prolonged stoppage but even then the cleaning process takes only a few seconds using a minimum quantity of detergents. The use of casting machines thus helps to economize considerable resources and ensures (with minimum wastage) effective environmental protection; and
- The various types of raw materials used in the casting machines are dosed in closed systems; the operating personnel hardly come into contact with the materials and thus phenomena such as gas accumulations, skin irritation, etc. do not arise.

2.4.2. Providing the Required Capacity

The technological unit should be designed for the given capacity while the casting

machine which ultimately determines the overall product yield should ensure this capacity.

In works producing large-sized structures or applying coatings on large areas, there are no problems associated with using highly productive casting machines since large volumes of polymer concrete can be processed quite rapidly. There are no problems whatsoever in selecting small casting machines (for producing small structures and products). Some difficulties can arise when producing a large number of small-sized products and structures using small moulds. In such cases, the capacity of the machine should, on the one hand, correspond to the overall required number of products and, on the other hand, should not exceed certain limits since polymer concrete fills small moulds more slowly than moulds with large sections and large charging holes.

Industrial plants of moderate size have been designed for processing aggregate fractions of size 3 to 7 mm since the size composition often used in producing polymer concretes covers this range and corresponds to an average wall thickness of about 20 mm of the products. Much larger units with greater capacity can handle fractions up to 16 mm, and some up to 40 mm granules.

When designing the casting machines, the hardness of the filler plays a secondary role since, on the one hand, modern machines are equipped with wear-resistant mixing components and can process solid material (granite, corundum, carborundum, etc.) and, on the other hand, the mixing process is carried out extremely carefully which poses no problem even when processing very brittle, light-weight fillers. The mixing components have high-strength surface coatings to a thickness of a few millimeters and can be restored as they wear out independent of the rest of the equipment. Therefore, delays associated with the restoration of these components are quite few.

When designing the mixing unit, dispersed fibre reinforcement mixed with polymer concrete mix should also be taken into consideration. When the machine is correctly designed, the addition of any reinforcing material to the polymer concrete mix (for example, fibreglass and carbon filament or shaped steel fibre) causes no difficulty in processing them in the polymer concrete mix.

The composition of the filler largely influences the structural design of the machines.

This factor is important for designing the dosing unit. Conforming to the varying physical and chemical properties of fillers, various systems are available at present for dosing light- as well as heavy-weight fillers. Fine-grained and free-flowing fillers should be processed differently than hard material, which often tends to cause congestion in the bunkers.

Fillers of mixed fractions are usually used for producing polymer concretes so that the application of the binder can be minimized. Often, the filler mixture is produced away from the casting machine (especially when using four or more fractions). Then, the casting machine can be equipped with only one container for storing the made-up filler material and a unit for dosing it. This ensures the storage of a certain amount of the filler and its addition in the required dose. When using two or three fractions of the filler, the machine should be provided with an adequate number of containers and dosing units so as to carry out preliminary mixing of the filler components before feeding them into the casting machine. A suitable method is selected in each individual case taking into consideration all the local conditions and after identifying all the constituents of the composition.

2.4.3. Materials

The binder systems for polymer mortar and concrete differ from those for ordinary cement mortar and concrete, but the aggregates are the same as those used for cement mortar and concrete.

2.4.3.1. Selection of Binder

Different resins used for producing polymer concrete, i.e., polyester, epoxide, vinyl ester, methacrylate. Poly-urethane, phenol, furan resins, etc., have specific characteristics. They differ from each other in density, viscosity and reactivity, and require different working temperatures for processing and also varying amounts of activators (hardeners).

Depending on the properties of the materials, various types of feeding and dosing systems of liquid constituents can be used. Specially fabricated gear-type pumps are predominantly used for dosing the resins. These prevent high friction coefficients and shearing stresses. The drive of the pumps can operate on direct as well as alternating current; preference is given to alternating current since such drives are

cheap and at the same time less sensitive to voltage fluctuations in the feed supply. When using alternating current drives, the control range is usually 1:10 but, by using transformers of alternating current frequencies, even wider ranges of control are possible. To ensure high dosing accuracy and to control the number of revolutions, transformers of alternating current frequencies are recommended. These help to mechanize the control of the number of revolutions and, when required, control automatically the number of revolutions with no time lag.

When using, for example, polyurethane and epoxide resins, the hardeners are processed by the same method as used for processing the resins. Only the capacity of the pumps requires to be matched with the required level of material flow.

When producing polymer concrete based on polyester or vinylester resins, the optimum method is to have two activators (catalyst as well as promoter) in the form of independent constituents, without mixing them with the resins when preparing the material manually. When storing the constituents separately, it is possible to regulate their consumption even in the course of producing the polymer concrete. This helps to modify at will the proportion of the constituents in the mixture with allowance for local conditions and operational requirements. When processing these resins, extremely small amounts of activators (about 2%) are added to the resin. Dosing should be extremely accurate and is ensured by using diaphragm pumps working at low pressures as different from piston pumps in which very high pressures are developed. In spite of the fact that diaphragm pumps, compared with piston pumps, operate with less intense pulsations, it has not been possible yet to eliminate them completely. Therefore, pumps in the suction and pressure lines are equipped with additional dampers to prevent pulsations and thus ensure smooth flow of liquid fractions into the system. The automatic control of the flow regime of liquid fractions with optical indicators ensures guaranteed, continuous and uniform flow of activators even at minimum volume of the material without giving rise to the phenomenon of pulsations.

The addition of activators using compressed air from suitable high-pressure reservoirs as practised in the plastics industry falls far behind the present level of technological developments. The flow regulation in this case is not sufficiently accurate while the high-pressure reservoir represents a source of great danger.

When processing methyl acrylate resins, the promoter is often already mixed in the resin composition while the catalyst is added in the form of a powder. For reasons given above, preliminary mixing of the accelerator is not recommended in principle, but even such binder systems can be processed in the casting machines. The hardener powder is fed either through a special powder feeding system into the mixer of the casting machine or (in the case of systems using premixed fillers) into the system of filler mixing. In the latter case, there is no need for a separate mixing system.

When processing epoxide and polyester resins, it is preferable to heat the resin in the casting machine to ensure a uniform product of high quality. For this purpose, the casting machine can be equipped with a heating apparatus working on the principle of heat exchangers and not on the direct heating principle. A heat exchanger provides a large heat transfer surface and hence the temperature difference between the heated apparatus and the heat carrier is not high. This eliminates the danger of sudden local overheating. Oil is used as a heat carrier in the heat exchangers. The oil, in turn, is heated in electric heaters. The circulation system ensures a constant circulation of the hot oil and maintains a constant temperature throughout the heat exchanger block.

The heating of the resin significantly reduces its viscosity, which ensures considerable economy of resin consumption, accelerates its thickening and increases the extent of hardening. All of these promote the product quality. Other resins (methacrylate, phenol, or furan), because of their low viscosity, require no heating whatsoever.

The construction material of pumps, pipe lines, valves, etc. should invariably conform to the requirements prescribed for working under conditions of aggressive chemical substances. While for processing resins and their constituents, the use of standard steel or cast iron is wholly suitable, high-alloy steels should be used for components handling activators. When using furan resins hardened by an extremely aggressive acid, the correct selection of the construction material is particularly important. The material used for fabricating packings and hoses should also be acid-resistant and stable to the action of powerful chemical reagents. Materials such as Teflon, Viton, polyethylene, and polyamide are most frequently used for these purposes.

When fabricating and installing electric equipment and pipe lines, the appropriate

requirements and specifications should also be satisfied, especially when processing methacrylate resins; in this case, safety of electric equipment and control system used for storing and handling the raw material and in the course of producing must be ensured. These measures are dictated by the extremely low ignition point of methacrylate resins.

In the industry, economy is a decisive factor. In accordance with the well-known rule that expenses should be the minimum required, casting machines have been fabricated for the specific binders used by a given customer. However, at present, in research organizations as well as in industrial plants, casting machines capable of processing various types of binders are required. Such flexibility is desirable for industries in which different systems of resins are processed and also for use in research institutions desiring to enlarge their capabilities. For example, if a consumer desires to work alternatively with polyester and epoxide resins, it is theoretically possible to use a single machine to process polyester resins which, after cleaning, can handle epoxide resins with no special problems. But, epoxide systems cannot be processed in machines intended for polyester resins since a large amount of hardeners is required.

Depending on the required content of hardeners, casting machines should be provided with dosing devices of various capacities. Optimum flexibility can be ensured when the casting machine has systems of feeding and dosing the various constituents. In this case, a switchover from one system of resins to another is possible without expensive cleaning and without risk of undesirable reactions between the different binders.

Synthetic Resins

Synthetic resins are usually supplied according to the agreement with the supplier in tank trucks of capacity 10-20 tones from which the resin is emptied into the containers of the consumer by pneumatic or built-in pumps. The unloading pipe lines are installed in such a way that they stand completely empty at the end of the unloading operation. If the pipe lines enter the container, a siphoning effect can be anticipated.

When pipe lines of long length are used to connect the tank truck with the container or when it is necessary to overcome large height differences, the diameter of the pipe

line should be 80-100 mm and sharp angles and bends should be avoided.

To ensure an optimum regime of raw material supply and to prevent interruptions in supply, the collector capacity should be not less than 150% of the volume of supply. To prevent the mixing of the remnants of the preceding batch of raw material with the new batch, an alternative solution is to install two containers, each holding the volume of normal supply.

Reservoirs made of alloy steel or pure aluminium are most suitable for storing synthetic resins. Steel containers are well recommended when the interval between the fillings is not longer than a few months. The containers are usually filled through the opening at the bottom when the gradient is normal. For measuring the liquid level in the container, devices using floats, lever indicators, or air bubble indicators are used. A thermometer is also recommended for measuring the liquid temperature, this being particularly important when the containers are placed in the open air.

To ensure more prolonged storage, material should be protected from light and heat. The most optimum storage temperature is 20°C with an upper limit of 25°C. At 15°C, increased viscosity of medium and highly viscous material may cause certain difficulties when emptying the containers and also when processing the material.

To ensure a stable temperature of the resin, the reservoirs should be placed in covered buildings with temperature control. When the containers are placed in the open, effective thermal insulation must be provided (to prevent any excessive cooling of the containers also) so that even when there is a temperature drop, the resin can be pumped through the pipe-line system to the casting machine. Further, the cross-section of the pipe line should take into consideration the viscosity of the resin handled and should be large enough for the travel of the material. The highly viscous epoxide resin, for example, requires large-sized tubes compared to the non-viscous liquid methacrylate resin.

Instead of one large reservoir, several small containers or some storage tanks can be used. These can be connected to the pipe line feeding the casting machine. When using several containers, each may be placed close to the casting machine and connected by a short length of pipe.

Activators

For storing activators, the appropriate instructions and guidelines should be strictly adhered to. Hardeners for epoxide, polyurethane and other resins are essentially regulated by the same requirements and recommendations already given while describing the resins. However, when considering these aspects for other systems of binders, some additional requirements should also be taken into consideration.

Fairly strong acids are often used as hardeners, for example, for furan resin. Therefore, the pipe lines for their storage and transmission should be made of high-quality alloy steels.

When processing polyester resins, the catalysts (liquid peroxides) and accelerators used for hardening should be stored separately. Large volumes of peroxides (over 200 kg) are stored in individual bunkers. The bottom should be made with some inclination in the form of a sump with a settler capacity of about 30 litres. Under certain conditions, the peroxide catalyst can be completely drawn from it. The bottom surface should be smooth and dense and must be amenable to easy cleaning. The closing doors made of steel sheet should open outwards. Slightly above the bottom, air intake lines of 30 cm x 30 cm with louvres should be provided in the side walls of the container. Provision should be made under the lid for additional air intake openings in the required numbers.

The internal dimensions of the storage building should be adequate for total operational safety with various types of containers in which peroxide is handled. The height of the building should be not less than 2.5 m. The capacity of the buildings can be raised by constructing stands with aluminium sections. Aluminium grills can be used as supports; they promote air circulation. Heating the buildings is usually not required in regions with warm climatic conditions; in fact, it is often necessary to provide cooling systems since the peroxide begins to boil and liberate gases at a temperature of roughly +28°C, which adversely affects their activity.

Some storage buildings for activators should be placed in such a way that the containers required in the process, i.e., those used while operating the casting machines, can also be located in them. Then, there will not be a single container with peroxide outside the storage house (with the exception of small amounts of

peroxide in the pipe lines connected to the casting machine).

2.4.3.2. Fillers

Fillers such as ground calcium carbonate, silica flour, and fly ash are used to extend polymeric binders and fill the very fine particles for aggregates. Ground calcium carbonate, which is the most common filler, cannot be employed in applications requiring acid resistance of the polymer mortar and concrete. The requirements for the fillers for the polymer mortar and concrete are as follows:

- Very low moisture content of less than 0.5% (because the moisture causes a reduction in the bond between most polymeric binders und aggregates)
- No impurities, which have a bad influence on the hardening reactions of polymeric binders
- Low absorption of polymeric binders
- Good rheological characteristic-improving effect as well as expectable extending and reinforcing effects on polymeric binders

2.4.3.3. Aggregates

Fine and coarse aggregates, such as river sands and gravels, crushed sands and stones such as andesite, limestone (or marble), and granite, silica sands, and sometimes artificial lightweight aggregates recommended for ordinary cement mortar and concrete, are dried to a suitable moisture content and ilscd for polymer mortar and concrete. The dried aggregates may be available at asphalt concrete plants. The requirements for aggregates for the polymeric mortar and concrete are as follows:

- Desirable partide shape and gradation to provide the highest possible absolute volume or the lowest possible void volume that will require the lowest content of polymeric binders to coat the aggregates and to fill the voids
- Soundness and high strength
- Very low moisture content of less than 0,5 or 1.0% (because the moisture reduces the bond between most polymeric binders and aggregates)
- No impurities, which have a bad influence on the hardening reactions of

polymeric binders

- Low absorption of polymeric binders

In general, the size and gradation of the aggregates are selected depending on the thickness of cover mortar or concrete or the depth of mortar or concrete to be placed, the type of applications, and the type of polymeric binders.

2.4.4. Mixing

To avoid heterogeneous mixing due to the rapid-hardening reaction and high-viscosity binder formulations (except for vinyl monomer-based binders), polymer mortar and concrete must be mechanically mixed using mixing equipment; mixing should never be done by hand.

Mixing equipment is classified into two types: discontinuous or batch mixers such as forced mixing-type mixers used for conventional cement mortar and concrete, and continuous mixers. The former are widely used in the world.

Mixer selection is generally dependent on the viscosity of the binder formulations and the applications of polymer mortar and concrete. As the polymeric binders are volatile and potentially explosive, no sparking and explosion proof mixers should be selected. Before the actual mixing of the polymer mortar or concrete, trial mixing should always be performed to determine the proper mix proportions. The standard mixing procedures using a forced mixing-type batch mixer for the polymer mortar or concrete are as follows:

- Aggregates and filler are sufficiently dry-mixed in a batch mixer.
- A polymeric binder is mixed with an initiator, promoter, or hardener at the required content in a proper vessel for 1 to 3 min, added to the dry mixed aggregate-filler mixture in the batch mixer, and mixed by the mixer for 3 to 5 min. Special care should be taken to prevent metering mistakes for the binder formulations.
- After mixing, the polymer mortar or concrete should be taken out of the mixer as soon as possible to prevent accumulated heat of the hardening reaction of the polymeric binder. The mortar or concrete adhering to the mixer should be cleaned out immediately.

2.4.4.1. Mix Proportioning

In principle, the mix design of polymer mortar and concrete is conducted by arranging aggregate gradation to provide the lowest possible void volume that will require the minimum polymeric binder contents necessary to coat the aggregates and to fill the voids, optimizing the properties of the polymer mortar and concrete. The polymeric binder contents are normally 9 to 25 wt%. The properties of the polymer mortar and concrete depend on largely the types and properties of the polymeric binders and the properties of the aggregates. The common procedures for the mix proportioning of the polymer mortar and concrete are as follows:

- Arrange aggregate gradation to give the lowest possible void volume or close-packed state by mixing the aggregates with different size distributions on the basis of continuous or gap grading.
- Mix aggregates that have the lowest possible void volume with a polymeric binder to make polymer mortar or concrete.
- Check up on the basic properties such as workability, bleeding or segregation, and strength of the polymer mortar or concrete, and decide the optimum mix proportions. Regardless of the polymeric binder types, the typical mix proportions (by weight) of the polymer mortar and concrete widely used are as follows:
- Binders to fillers to fine aggregates = 1 (0 to 1.5) : (3 to 7) for the polymer mortar; binders to fillers to fine and coarse aggregates mixtures = 1 (1 to 1.5) : (8 to 8.5) for the polymer concrete.

2.4.5. Placing and Curing

Fresh polymer mortar and concrete are placed and finished in a similar to conventional cement mortar and concrete. Depending on their applications, the polymer mortar and concrete are cast into molds or forms, and the polymer mortar is often troweled as surface coatings or linings.

In the cast-in-place applications of polymer mortar and concrete, it is very important to do elaborate surface preparation of various substrates as is done with polymer-

modified mortar and concrete. The most important point about the surface preparation is the control of the moisture content of the cement mortar and concrete substrates. Moisture on the mortar and concrete surfaces should be removed unless no influence of the moisture on the adhesion of the polymer mortar and concrete is known. The moisture content of such substrates should commonly be controlled to less than 8 to 10%. A high-frequency moisture meter is often used to determine the moisture content. The cement mortar and concrete substrates are naturally dried under ambient conditions or forcibly dried using gas-fired torches, etc. Furthermore, suitable primers are usually applied on the dried surfaces by brushes, rollers, or sprays. It is advisable to apply the coating or lining to thicknesses of about 5 to 10 mm. If a greater thickness is required, the same troweling work is repeated until the required thickness is achieved. Usually placed or lined surfaces in polymer mortar and concrete are more difficult to finish by troweling than in conventional cement mortar and concrete because of wet drag. When forms are required in the placement of the polymer concrete, conventional wooden or steel forms treated with effective mold-release agents such as silicone wax, oils or greases, paraffin wax, vegetable oils, or polyethylene sheets can be employed. The mold-release agents should be selected corresponding to the type of the polymeric binders. The thickness of the polymer concrete to be placed once depends on the type of the polymeric binders, the amount of heat developed during the hardening process, ambient temperature, etc. The desirable thickness is generally about 5 to 10 cm, and the maximum thickness is 30 cm. The placement at thicknesses exceeding 30 cm may cause defects such as cracks due to the accumulation of the heat. The polymer concrete should be placed as speedily as possible and sufficiently consolidated by using suitable vibrators for conventional cement concrete. Then the placed polymer concrete surfaces are smoothly finished by use of trowels.

In the cast-in-place applications of the polymer mortar and concrete, prepacked-type (in which a liquid resin as a polymeric binder is poured into prepacked aggregates) and prepackaged-type (in which two packages are supplied, and their contents are mixed in the field) products tend to be widely used. In the precast applications of the polymer mortar and concrete, various molding processes such as casting, centrifugal molding, compression molding, and extrusion molding are applicable. Molding process selection depends on the type of polymeric binders used, the shape, size, and

output of products. In general, the casting or centrifugal molding process is applied to produce large structural members.

Because polymer mortar and concrete generally have an excellent adhesion to various materials, all the equipment and tools such as mixers, trowels, shovels, and vibrators should be cleaned immediately after use or at least within their working life. The cleanup of such equipment and tools can be done by rinsing with a suitable solvent such as methyl chloride, xylene, or methyl ethyl ketone, or by wiping with a rag saturated with such a solvent. In particular, the mixers are effectively cleaned by rinsing with the solvent, followed by operating them with a load of coarse aggregate.

Polymer mortar and concrete can generally be placed in a temperature range of 0 to 50°C. Polymer mortar and concrete using methyl methacrylate-based binders can exceptionally be placed at temperatures of -20 to -25°C. In the applications of polymer mortar and concrete, polymerization and curing processes are usually accomplished through an initiator-promoter system. The polymer mortar and concrete are subjected to ambient temperature cure, heat cure, or combined ambient temperature and heat cure. It is most important that the developments of mass production systems for precast polymer concrete and of automated application systems for cast-in-place polymer concrete should aim at cost reduction and that a good balance between economy and performance should be achieved.

2.4.6. Production and Use of Moulds

Finished polymer products are usually produced by casting, which requires the use of moulds in which the liquid or paste-like polymer concrete slurry is cast and hardened. In designing the moulds for polymer concrete products, the same aspects as in other casting processes should be taken into consideration.

2.4.6.1. Mould Section

Moulds should have openings through which the polymer concrete slurry can be quickly filled. Further, the shape of the mould and the surface properties of the mould material should ensure rapid flow of the solution within the mould. Only by fulfilling these conditions is it possible to ensure an economic production regime of polymer concrete products. Too many narrow inlets in the mould lead to clogging of the mould inlet and adherence of the polymer concrete to the edges of the mould

during continuous operation of the casting machines. This causes not only loss of material but also much contamination of the production areas. Very narrow mould sections may disturb the uniform distribution of the polymer concrete mass throughout the mould and result in poor-quality sections in the finished products.

Single sections of moulds prevent temperature differences during the exothermal process of hardening and hence differences in thermal and shrinkage stresses which may lead to the deformation of finished polymer concrete products.

When making moulds, special attention should be paid to complete removal of air from the mould and polymer concrete mass during the process of filling and during compaction of the polymer concrete mass. Depending on the shape of the product and the section of the outlet, it might be useful to provide a few openings in the moulds for air release as in the case of moulds used for metal casting.

2.4.6.2. Striking (Demoulding)

For efficient production of polymer concrete and also in view of the rapid reactivity of polymer concrete mass, the process of striking should be automated or (when working manually) the proportion of manual work reduced to a minimum. The use of fasteners in the form of spring tension members, clamps or holders is recommended as their operation is very simple and quick compared with screwed joints. There is no doubt that the basic requirement is to ensure stable and firm adhesion of the constituent parts of the mould.

Striking is also simplified and improved by slanting the sides of the mould slightly inwards. This is particularly important when using monolithic and three-dimensional moulds into which the polymer concrete mass can be pressed in a hot state during hardening. The slope of the mould should be not less than 3° . A higher conicity helps obtain even more effective results.

When the moulds consist of several parts, there is no danger from hot pressing but, in this case, striking should be carried out in stages.

Whenever possible, the mould should be designed in such a way that striking of the inner mould can be carried out first followed by the outer mould. Thus, the outer mould performs an additional function of protecting and strengthening the product which so far (by the time of striking) has not yet totally hardened. However, the inner

mould withstanding free shrinkage has already been removed. At the commencement of shrinkage, the outer mould is very easily removed since the finished product comes out spontaneously from the outer mould due to shrinkage.

When producing products without an inner mould, for example, plates, panels, or other homogeneous massive products, no special problems arise during striking. It is best to wait for the moment when the product detaches itself from the mould and can be removed freely. The casting mass in no case should flow from the mould onto the outer surface. This phenomenon leads to the formation of 'hooks' during striking that have to be chipped away from the finished product or striking becomes impossible.

2.4.6.3. Compaction and Transport

To ensure the maximum homogeneity and density of the finished product, high-quality compaction is necessary. However, the effect of even the most productive compaction units will be restricted if the moulds are not designed for the appropriate compaction processes or cannot support loads during compaction, it is especially important to achieve a situation wherein, during vibration compaction, forces acting on the mould will also act on the polymer concrete mass. This becomes possible only when the moulds can effectively transmit the vibration forces to the polymer concrete mass. The moulds should therefore be placed correctly on the vibrator and fixed if necessary. When using vibration tables for compaction, the mould should have a smooth bottom surface and, when using vibration pedestals, the mould surface should be uniform at places which rest on supports.

Insufficient rigidity of mould walls may lead to shake up of the mould during compaction by vibration and cause leakage of air into the mould and into the polymer concrete mass. Quite often, this problem arises not when using vibrators but when using suspended vibration compacting devices. Under compacted masses at the corners and edges of the mould also lead to the penetration of air into the polymer concrete mass and to the leakage of the liquid binder. Both these phenomena lead to edge defects in the finished products and give rise to serious problems during striking, necessitating additional work at the finished stage.

2.4.6.4. Material for Preparing Moulds

For preparing moulds, extremely diverse materials are used, such as wood, steel, alloy steel, aluminium, glass-reinforced plastics, synthetic rubber based on

silicone, polyethylene, Teflon, etc.

For producing special products, prototypes, or a small number of articles, wood is the most optimum material for making the moulds. Wood is a very cheap material compared to metal or plastics but is inferior to them in its durability and hence is less suitable for large-scale production of polymer concrete products. For producing decorative finishing plates and panels, splint-slabs are well recommended for making the moulds (melamine resins are used for coating) since moulds made of these materials are not damaged in the course of use or during striking. The alternative materials, for example corrosion-resistant steel or plastics, are not only more expensive, but also generally very heavy. They should either be relatively thick or have stiffeners to avoid warping.

The surfaces of the finished polymer concrete products produced represent an accurate copy of the mould surface. Products with a lustrous surface are produced in moulds whose surfaces have been polished by an appropriate method. The polishing of wood is practically impossible while polishing of steel is expensive. Decorative articles with lustrous polished surfaces are produced in moulds made of plastic material reinforced with fibreglass which maintains the surface lustre for a long time and, when required, can be additionally polished. Such moulds possess an additional advantage in that they can be copied from any finished product or from a model. Thus moulds of practically any shape, without joints that would leave a mark on the finished product, can be produced.

Aluminium moulds are used for producing a large series of polymer concrete articles, primarily in such cases when the moulds themselves are produced by casting. Considerable expenses are involved only for making the model. From this model any number of moulds can be produced later without much expense. The use of aluminium moulds has yet another advantage, namely, the casting skin is not completely removed from the mould and supports the action of the separating layer (lubricant) and facilitates striking. It is well known that the hardening of polymer concrete is an exothermal process. This fact should invariably be taken into consideration when preparing the moulds. The greater the wall thickness of the product, the greater the proportion of binder in the polymer concrete mass and thus the greater the amount of heat liberated during hardening. The temperature can go up

to 50-60°C (which is wholly permissible) and hence the mould should be heat-resistant.

Defects and some problems arise also when the moulds are made by gluing several components together in spite of using glues of appropriate thermal resistance.

For commercial production, the most suitable moulds are those produced in such a way that the polymer concrete products are obtained in a single operation. This involves a certain amount of complexity and expense in mould preparation but these are compensated by eliminating the additional processing of moulds as, for example, for producing products of complicated shapes. However, during the production of prototypes or a small number of products as, for example, when producing large-sized members and structures, it may be technically and economically effective if such structures are produced not in one single operation in the form of monolithic castings, but are divided into constituent members and made in small or less expensive moulds and later assembled into the finished structure. The most optimum technology of joining the constituent members into the finished structure is screwing or gluing. Holes can be made or if necessary provision for screwing in the threads can be made in the body of the mould and cast with no special problem.

2.4.6.5. Separating Layer for Mould

Depending on the material used for making the moulds and also the required surface quality of the products, it is necessary to apply a separating lubricant to prevent the sticking of the binder to the mould and thus ensure rapid striking. The separating material is selected after suitable investigations before producing the polymer concrete product. Many companies producing polymer concrete once underestimated the importance of the separating layer and only adverse experience compelled them to recognize in full measure the importance of this material. The presence of cracks and breakage of bits from the finished articles are not merely the adverse consequences arising from the absence of separating layers when producing polymer concrete products, but also result from incorrect selection of this material. An incorrectly selected separating material (or ineffective separating layer) may break the mould right in the first attempt at moulding the product.

The separating layer is intended not only to prevent the sticking of the binder to the mould surface, but also to cover up any possible pores on the surface of the product,

cavities in the moulds, slits at the joints, and also to prevent the penetration of the hinder or the polymer concrete mass into these cavities. The coarser and more porous the material from which the mould has been made, the greater should be the viscosity of the separating layer and the thicker the separating material layer applied on the mould. Thus, moulds made of wood are treated with wax before filling with the polymer concrete mass; wax also functions as a separating layer. But the surface of the casting cannot be expected to be lustrous in this case.

A lustrous surface in moulds calls for the use of very thin separating layers. For this purpose, polishing wax or pastes are used (after applying, they are almost completely rubbed in): liquid separating materials are also capable of imparting some lustre to the mould surface. There are also some so-called 'internal separating materials', i.e., material is added to the binder itself which prevents its adherence to the mould surfaces and eliminates having to process the mould surface directly with a separating material. However, such materials are not well recommended in practice. A definite separating effect is possible only when an extremely thin layer of the internal separating material (gel coat, a gel-forming layer) is deposited. Whether such a separating layer is adequate for ensuring a high-quality article and whether it has a positive effect on the mould, it is difficult to predict. In any case, there is real danger of insufficiently effective separation and hence the breakage of finished articles during striking cannot be eliminated.

Other criteria for selecting the separating material are thermal stability and rapid drying, for example, by the action of air. The entry of the solvent present in almost all the separating layers onto the upper layer of the polymer concrete or deep into the mass should be prevented, as it may cause difficulty during hardening and also visual defects on the surface of the polymer concrete. Moreover, the separating material should be firm enough not to be dislodged from the mould surface under the action of the polymer concrete mass; otherwise it will be practically ineffective during striking. This danger is particularly imminent when coarse fillers are present.

The desire to develop a universal separating material that could be used for all mould materials and for all binder systems, functioning effectively and uninterruptedly, is quite understandable, but such a material is hardly possible. A separating material which is closest to all these objectives is polyvinyl alcohol, a watery liquid forming a

film on the mould surface which acts as a genuine separating layer. The main advantages of polyvinyl alcohol are: it can be used on almost all the materials from which moulds are produced; even while applying the material on the mould surface, the quality of the separating layer can be visually judged since, for example, on surfaces containing fats it is generally impossible to produce a good and compact separating layer and the polyvinyl alcohol will actually flow off the mould surface; the application of a uniform separating layer makes for ease in striking; polyvinyl alcohol is available in various shades and hence a grade of alcohol matching with the colour of the mould surface can be selected and, finally, the phenomenon of binders sticking to the mould can be avoided.

The main difficulty in handling polyvinyl alcohol arises when it is applied in an excessively thick layer that requires a very long period of drying. Polyvinyl alcohol contains a significant amount of water and its hardening takes considerable time (only a hard layer can withstand the action of a polymer concrete mass cast in the mould). The thicker the layer of polyvinyl alcohol, the longer the period required for drying. It would be incorrect to assume that because the surface layer of the polyvinyl alcohol hardens rapidly, the underlying layers too have dried; in fact, the deeper layers take a relatively longer time for drying. The hardness of the layer can be felt with the fingers, giving an idea of the state of the surface layer. Therefore, it is very important to apply polyvinyl alcohol in an extremely thin layer (to the extent possible) so that it dries well under the action of air and hardens.

Moulds of polyethylene, Teflon, and similar materials can be used entirely satisfactorily with no separating layer. The use of such materials is limited, however, because of their high cost.

2.4.6.6. Compaction of Polymer Concrete

When compacting a polymer concrete mass, the very same principles as in other similar fields, for example, in cement concrete production, are applicable. Polymer concrete can be compacted by compression, vibration or centrifugal force (as done when producing products having a circular section, for example, pipes), or also by centrifuging or compression by rollers. It is important that the viscosity of the polymer concrete mass matches totally with the selected compacting technology. Only then are positive results possible.

However, in practice, preference is given to vibration compaction since this is a universal technology well recommended for materials ordinarily used for producing polymer concrete. The criteria which should invariably be taken into consideration during vibration compaction of polymer concrete are given below.

In the process of compaction, the following principle is *not* applicable: 'The longer the vibrations, the better the compaction of the mass and hence the better the quality of the finished product.' It is essential to recognize and keep in mind that vibrations over a prolonged period are fraught with adverse consequences for the end product. Very heavy and coarse fractions of the filler descend more rapidly than the much finer and lighter fractions and hence there is danger of stratification throughout the section and, since the much smaller fractions of the filler have a greater specific surface, the upper layer of the mass is bound with a greater amount of the resin than the lower portion consisting of coarse fractions of the filler. The uneven distribution of the binder throughout the mass makes for uneven shrinkage, which might lead to warping and bending of the finished product. This danger is particularly high when producing large-sized products, for example, plates (slabs) or panels.

Compaction may also have an adverse consequence if vibrations are prolonged after gel formation of the polymer concrete mass has begun, i.e., at the commencement of the hardening reaction. If in this case, vibration compaction is continued, there is danger of decompaction of the mass, leading to a heterogeneous polymer concrete mass.

In polymer concrete production, vibrating motors with pneumatic or electric drives are used. The advantage of vibrating systems with pneumatic drives is the fairly simple control of the frequency of vibrations by reducing or increasing the air supply. The drawbacks of these systems are the extremely insignificant oscillating forces (amplitudes), high level of noise during operation and the large consumption of air. Therefore, a large number of consumers are more favourably inclined to use electric drives, usually without a frequency control system since the latter is expensive. The consumer generally produces compaction at normal (about 3000 rpm) or at maximum frequencies (about 6000 rpm). Further, several cases are known in which the vibration tables, used for compaction, were operated alternately on normal or high frequencies. Which level of frequency is most optimal is a question to be

examined for each individual case.

The vibration force should be adapted in each case to the mass of the casting and the mould. When using vibration systems with an electric drive, this poses no complexity and requires only the control of the eccentric discs.

The most popular method of transferring the compacting force to the polymer concrete mass is to place the mould in the process of filling it with the polymer concrete on the vibration table in such a way that the force applied acts downward. Vibration tables are universal; in other words, using vibration tables, the mass can be compacted in almost any mould. Instead of vibration tables, vibration pedestals or vibration frames could also be used but the latter should be adjusted more accurately to the dimensions of the finished moulds. In a continuous production regime, two moulds are generally placed on the vibration table at the same time, one each at the beginning of filling and at its completion (i.e., after filling the second mould), and thus two moulds can be compacted simultaneously.

Instead of vibration tables, suspended vibration systems may also be used. These are directly connected to the mould with screws or clamps, for example. This method is well recommended only when producing large-sized products wherein filling the mould is protracted, when working with one or several moulds, and also when working with vibration systems with a pneumatic drive that does not involve much expense, and for producing large numbers of products. The main working conditions required for the latter is the availability of rigid moulds which do not bend inward.

There is also a third method of compacting the polymer concrete mass in moulds, i.e., by using manually operated internal vibrators which are inserted directly in the polymer concrete mass and are withdrawn from the mass in good time just before the commencement of hardening. This method is suitable mainly for those consumers who use manual vibrators for other purposes, i.e., these are already available. Implementation of this method requires an additional power source since these vibrators are controlled only manually. The use of vibrators is also limited to the section of the mould inlet. Manual vibrators are also appropriate when used as ancillary vibrators whenever the main process of compaction is done on a frame, pedestal or table. Later, sections of the mould in which the polymer concrete mass requires special compaction, can be compacted using a manual vibrator.

The compaction of a polymer concrete mass upward, i.e., with the help of vibrators placed under the mould, is not recommended. The work of the vibrators in this case is less effective since they cannot produce sufficiently intense compaction. However, such methods can be used as ancillary operations, for example, to obtain a smooth and even surface on the backside of the casting.

Some vital errors that creep in during the compaction of a polymer concrete mass are given below:

- Vibration tables or frames are not sufficiently rigid and hence the vibration forces are non-directional; with insufficiently rigid structures, the vibration energy does not enter the polymer concrete but is converted into kinetic energy of the supporting structure of the vibration table or frame; after prolonged working, this causes fatigue of the material constituting the support;
- Intense noise is produced if the moulds are not properly secured on the table (especially when the moulds or the table are made of metal); with the help of a simple mechanism (pneumatic or hydraulic) controlled by a switch, the mould can be fixed to the table or to any other support surface; thus not only the noise level is reduced but the application of force to the polymer concrete mass can be directed as required and compaction improved;
- Several components subjected to vibration simultaneously also increase noise and wear; this is relevant when guide rolls on which the moulds are transported are also involved in vibration; this can easily be corrected by using vibration pedestals which in the course of vibration are shifted between the rolls with the help of a pneumatic or hydraulic mechanism; the roller conveyor can be placed below the vibrating pedestal;
- When using several vibrating motors simultaneously on a single mould or on frames of a single vibrating system, special attention must be paid to ensure that the vibrators rotate in the same direction; the different vibrators should supplement each other as otherwise simple mixing of the polymer concrete mass will result without compaction.

2.5. Properties of Polymer Mortar and Concrete

Polymer mortar and concrete have a microstructure in which the cement hydrate binders of conventional cement mortar and concrete are completely replaced with polymeric binders, and therefore, they develop characteristics that are very different from those of the cement mortar and concrete. The properties of the fresh and hardened polymer mortar and concrete are affected by factors such as polymeric binder types, binder formulations and mix proportions, and curing conditions.

2.5.1. Properties of Fresh Mortar and Concrete

2.5.1.1. Workability

In general, polymer mortar and concrete provide a worse workability than conventional cement mortar and concrete because of the high viscosity of their polymeric binders. As an exception, the workability of polymethyl methacrylate (PMMA) or acrylic mortar and concrete using a low-viscosity methyl methacrylate monomer is similar to that of the cement mortar and concrete. As the working life (or pot life) of the polymer mortar and concrete is commonly short, their workability is apt to change in a short time.

2.5.1.2. Working Life and Hardening Time

The working life (or pot life) and hardening time of polymer mortar and concrete at ambient temperature can be widely controlled by selecting suitable initiators, promoters, or hardeners, which are added to polymeric binders. Generally, the polymer mortar and concrete harden rapidly compared to ordinary cement mortar and concrete. Rapid hardening is one of their great advantages. When forms or molds are used, they can be removed within about 1 to 3 h after the placement. Accordingly, molds can be reused easily in factories that manufacture precast products, and labor-saving placement is possible in field applications.

2.5.1.3. Bleeding and Segregation

Generally, polymer mortar and concrete have a good resistance to bleeding or segregation because of the high viscosity of polymeric binders. As an exception, PMMA mortar and concrete, similar to conventional cement mortar and concrete, have the potential to bleed or segregate because of the low viscosity of their

polymeric binders.

2.5.1.4. Setting or Hardening Shrinkage

Like the large drying shrinkage of ordinary cement mortar and concrete, the large setting or hardening shrinkage of polymer mortar and concrete is a problem to be considered in their practical applications. Their setting shrinkage reaches about five to ten times the drying shrinkage of the cement mortar and concrete. The large setting shrinkage may affect the accuracy of molding or placing, the design of forms or molds, and the adhesion or bond to reinforcements or substrates. if necessary, the use of effective shrinkage-reducing agents is recommended, depending on the polymeric binder type, molding, or placing process and application.

2.5.2. Properties of Hardened Mortar and Concrete

2.5.2.1. Strength

Polymer mortar and concrete develop very early high strength compared to conventional cement mortar and concrete. Such a high strength development makes possible the weight reduction of precast products due to their reduced cross-sections. Table 2.7 gives the physical properties of typical polymer concretes. Since the polymeric binders have high strength and superior bond or adhesion to the aggregates, the strength of the polymer mortar and concrete are apt to depend on the strength of the aggregates. Regardless of the type of the polymeric binders, moisture contents exceeding 0.5 to 1.0% of the aggregates cause a marked reduction in the strength of the polymer mortar and concrete. Therefore, special care should be taken to control the moisture content of the aggregates. Since the polymer mortar and concrete contain the polymeric binders with poor thermal resistance, the temperature dependence of their strength is high at temperatures of 50°C or higher, as seen in Figure 2.2. This trend is remarkable in PMMA or acrylic mortar and concrete using a thermoplastic resin as a polymeric binder. The maximum temperature limit for the retention of useful strength properties of the polymer mortar and concrete is primarily governed by the glass transition point of the polymeric binders, and ultimately by their thermal degradation. Consequently, irrespective of the type of the polymeric binders, the maximum temperature limit is found to be approximately 50°C in their structural applications. The polymer mortar and concrete using

common polymeric binders are difficult to set or harden below 0°C. As shown in Figure 2.3 however, PMMA mortar and concrete using methyl methacrylate-based binders with excellent low-temperature curability develop a compressive strength of about 500 kgf/cm² within 1 h after placing at -20°C.

Table 2.7 Physical properties of polymer concretes (Chandra, S., Ohama, Y., 1994).

Physical Properties of Polymer Concretes								
Physical property	Type of polymer concrete						Reference	
	Furan concrete	Polyester concrete	Epoxy concrete	Polyurethane concrete	Phenol concrete	Acrylic concrete	Asphalt concrete	Ordinary cement concrete
Unit weight (kg/m ³)	2200 ~ 2400	2200 ~ 2400	2100 ~ 2300	2000 ~ 2100	2200 ~ 2400	2200 ~ 2400	2100 ~ 2400	2300 ~ 2400
Strength (kgf/cm ²)								
Compression	700 ~ 800	800 ~ 1600	800 ~ 1200	650 ~ 720	300 ~ 600	800 ~ 1300	20 ~ 150	100 ~ 600
Tension	50 ~ 80	90 ~ 140	100 ~ 110	80 ~ 90	30 ~ 50	70 ~ 100	2 ~ 10	10 ~ 50
Flexure	200 ~ 250	140 ~ 350	170 ~ 310	260 ~ 230	150 ~ 200	150 ~ 220	20 ~ 150	20 ~ 70
Modulus of elasticity (×10 ⁴ kgf/cm ²)	20 ~ 30	15 ~ 35	15 ~ 35	10 ~ 20	15 ~ 20	15 ~ 35	1 ~ 5	20 ~ 40
Water absorption (wt%)	0.05 ~ 0.3	0.05 ~ 0.2	0.05 ~ 0.2	0.3 ~ 1.0	0.1 ~ 0.3	0.05 ~ 0.6	1.0 ~ 3.0	4.0 ~ 6.0

2.5.2.2. Deformability, Elastic Modulus and Creep

Like conventional cement mortar and concrete, polymer mortar and concrete generally exhibit a nearly linear stress-strain relationship up to almost maximum stresses, as shown in Figure 2.2, and show a large temperature dependence of the relationship. As seen in Table 2.7, the modulus of elasticity of the polymer mortar and concrete is much the same as or slightly less than that of the cement mortar and concrete. The creep of the polymer mortar and concrete depends on the type and content of the polymeric binders, and is considerably temperature-dependent as are their other properties. However, their creep is about the same as that of the cement mortar and concrete at room temperature. Figure 2.4 shows the creep behavior of polyester and epoxy concretes. Except for the polymer mortar and concrete with the extremely high content of polymeric binders, the thermal expansion coefficient of the polymer mortar and concrete is approximately 10×10⁻⁶ /°C and almost the same as that of the cement mortar and concrete. As mentioned above, it appears that the deformation characteristics of the polymer mortar and concrete are essentially influenced to some extent by the viscoelastic behavior of the polymeric binders used.

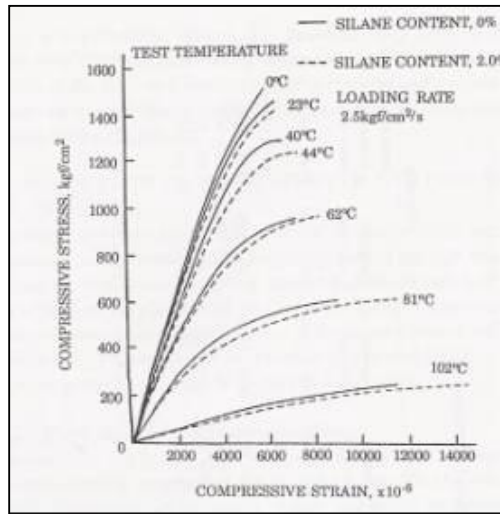


Figure 2.2 Effects of test temperature on compression stress-strain curves for polyester concrete (Chandra, S., Ohama, Y., 1994).

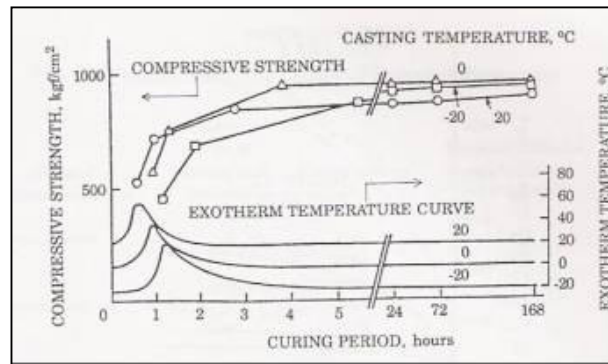


Figure 2.3 Curing period vs. compressive strength and exotherm temperature of polymethyl methacrylate (Chandra, S., Ohama, Y., 1994).

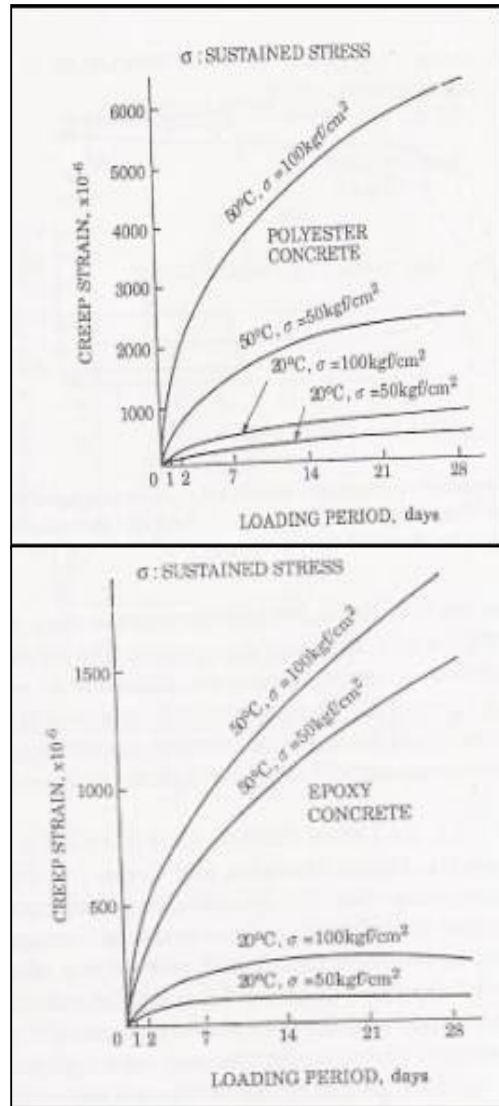


Figure 2.4 Creep of polyester and epoxy concretes (Chandra, S., Ohama, Y., 1994).

2.5.2.3. Water-tightness, Gas- Tightness, Freeze- Thaw Durability, and Water Resistance

Most polymer mortar and concrete have an almost completely impermeable microstructure, and they exhibit excellent resistance to water or moisture absorption, moisture, and air or gas permeation. Since the polymer mortar and concrete hardly

contain water or moisture and water penetration to the inside does not take place, their freeze-thaw durability is superior, as shown in Table 2.8. The water absorption of the polymer concrete is indicated in Table 2.7 in general, the polymer mortar and concrete have good water resistance. It is sometimes feared that polyester mortar and concrete are not sufficiently water resistant; the concern is potential degradation due to the hydrolysis of unsaturated polyester resin as a polymeric binder. However, the water resistance of polymer mortar and concrete is found to be good unless they are exposed to boiling water.

Table 2.8 Freeze- Thaw Durability of polymer concretes (Chandra, S., Ohama, Y., 1994)

Freeze- Thaw Durability of Polymer Concretes				
Type of polymer concrete	Number cycles of freezing and thawing	Weight change (%)	Dynamic modulus of elasticity ($\times 10^4$ kgf/cm ²)	Flexural Strength (kgf/cm ²)
Epoxy concrete	0	-	28.3	173
	100	0.04	28.1	170
	300	0.07	25.6	170
Polyester concrete	0	-	33.6	227
	100	0.06	33.6	224
	200	0.14	33.6	-
	300	0.15	33.1	-
	400	0.18	32.7	217
Polyurethane concrete	0	-	18.3	193
	100	0.09	17.4	184
	300	0.18	16.9	179

2.5.2.4. Chemical Resistance

Since polymer mortar and concrete have a watertight or impermeable microstructure

without low chemical-resistant ingredients like cement hydrates, they generally have a high chemical resistance compared to cement mortar and concrete, as indicated in Table 2.9 Such a high resistance is dependent on the nature and amount of the polymeric binders, the properties of the aggregates, and the nature of chemicals used. Their resistance to oxidizing agents is inferior.

Table 2.9 Chemical resistance of polymer concretes (Chandra, S., Ohama, Y., 1994)

*10 points for excellence, 1 point for failed

Type of polymer concrete	Evaluation value (points*)				
	Acid	Alkali	Salt	Solvent	Oil and fat, mineral oil
Polyester	8 – 9	3 – 4	9 – 10	4 – 6	7 – 9
Epoxy	9 – 10	9 – 10	10	6 – 7	9
Furan	9 – 10	9 – 10	10	7 – 8	8
Acrylic	8 – 9	8 – 9	9 – 10	5 – 6	7 – 9
Cement	1	8 – 10	1 – 7	5 – 7	7 – 10

2.5.2.5. Abrasion Resistance, Impact Resistance, and Electrical Insulating Properties

Most polymer mortar and concrete exhibit good abrasion resistance, impact resistance, and electrical insulating properties compared to conventional cement mortar and concrete, though such properties are affected by the type and properties of the polymeric binders used.

2.5.2.6. Incombustibility and Fire Resistance

Polymer mortar and concrete containing combustible polymeric binders generally provide poor incombustibility and fire resistance, depending on the type and amount of the polymeric binders. For the purpose of improving such essential disadvantages, the necessary content of the polymeric binders is controlled to a minimum by volume, and effective flame retardants are added to them.

2.5.2.7 Weatherability, Weather Resistance

In general, polymer mortar and concrete are found to have poor weatherability or weather resistance like polymer-modified mortar and concrete, since they contain polymeric binders, which seem to give a poorer weatherability than inorganic

materials such as cement mortar and concrete. However, this is not necessarily true. Figure 2.5 demonstrates the weatherability of polymer mortar and concrete through eight years of outdoor exposure. The compressive strength of most polymer mortars and polyester concrete under outdoor exposure conditions tends to become nearly constant at one year or more. From these test results, it seems reasonable to discount the general view that their weatherability may be limited because of the poor weatherability of their polymeric binders. Consequently, most polymer mortar and concrete are considered to have service lives of 20 years or longer under moderate outdoor exposure conditions.

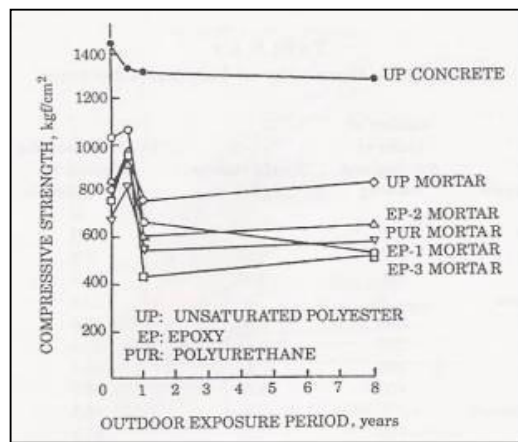


Figure 2.5 Weatherability of polymer mortars and polyester concretes (Chandra, S., Ohama, Y., 1994)

2.5.2.8. Heat and Fire Resistance

The polymer binders of PC products are organic substances, which are known to have much lower heat resistance than inorganic materials such as stone, cement and metals. Thus, prolonged exposure to elevated temperatures is not recommended, as it causes degradation of the resin and eventual loss of strength. The heat resistance of PC products depends on the type of polymer binder. For polyester and epoxy PC, the safe working temperature limit is about 60°C for continuous exposure.

Behaviour under fire is very important in applications in which PC materials are used as facing elements or for interior decoration. PC materials do not burn easily because they have high mineral filler content. Their behaviour under fire can be further improved at relatively small cost by incorporating fire-retardant additives.

3. EXPERIMENTAL PROCEDURE

3.1. Selection of the Resin

Thermosetting Polyester resin is selected as a result of being more economical and widely available. The principal advantage of polyester resins is the ease in which they may be fabricated, a consequence of polymerization via a free radical reaction. Such reactions are rapid and easily controllable, thus production cost is relatively low.

The data sheet of the polyester used in the experimental work “Şişecam CE 92 N8” is given in Appendix A-1.

3.1.1. Properties of Unsaturated Polyester (UP)

UP Resins are most commonly used as composite materials. These polymers are made up of at least two separate components; reinforced fibre and embedding matrix. Other additives may be used to improve properties or characteristics. Carbon, aramide or most commonly glass fibres may be used yielding FRP (Fibre Reinforced Plastic) or specifically GRP (Glass Reinforced Plastics) in the case of glass. Materials basically bridge the gap between conventional, commodity plastics and specialist engineering plastics. Production takes place by introducing reinforcement while the resin is in an uncured, liquid state.

The unsaturated polyester resins used in thermosetting alkyd and polyester molding compounds are made by the reaction of polyols with dibasic organic acids. Unsaturated acids (maleic anhydride or fumaric acid) and saturated acids (phthalic anhydride, isophthalic acid, adipic acid) are both used. Commonly used polyols include propylene glycol, ethylene glycol, diethylene glycol, and neopentyl glycol. Thus, a wide range of polymers can be made by this reaction. The most important cross-linking monomer is styrene. Monomers other than styrene used in unsaturated polyesters include methyl methacrylate (enhanced weather resistance), butyl methacrylate (enhanced weather resistance), vinyl toluene (less volatility), diallyl

phthalate (very low volatility, prepregs), diallyl isophthalate (very low volatility, prepregs), octyl acrylamide (solid monomer, molding compound), trimethylol propane triacrylate (ultraviolet and electron beam cure), and triallyl cyanurate (high heat deflection).

Alkyd and polyester molding compounds also include bulk molding compound and sheet molding compound. The form of the material is dependent on end-use requirements and is supplied as free-flowing pellets, extruded logs, continuous rope, or in bulk form.

Alkyd polyesters have excellent electrical properties and show outstanding retention of dielectric strength at elevated temperatures. The physical properties can be significantly varied by the formulation and molding method. Molding compounds have flexural strength in the range of 55 to 165 MPa (8 to 24 ksi), while tensile strength is in the range of 35 to 105 MPa (5 to 15 ksi). Impact strength depends on fiber loading and length in the range of 20 to 37 J/m (0.4 to 0.7 ft . lbf/in.) for granular products. The Izod impact strength for pelletized polyester can be as high as 55 J/m (1 ft . lbf/in.). The impact strength of bulk molding compound ranges from 55 to 430 J/m (1 to 8 ft . lbf/in.).

Alkyd and polyester compounds are molded by compression, transfer, injection, and runnerless injection/compression molding processes. Molding temperatures depend on the choice of the catalyst and range from 165 to 180 C° (330 to 360 F°). Without sufficient heat, the system will not cure; therefore, high heating capability is needed in the mold.

Alkyd and polyester molding compounds must have a combination of good electrical, mechanical, and dimensional stability).

Molding techniques include press molding, for example, compression, injection, pultrusion, and transfer. Contact molding processes include hand lay-up, spray-up, filament winding, and centrifugal casting.

In compression and injection moldings, sheet molding compound and bulk molding compound are used. The curing is done at an elevated temperature and at a relatively high pressure. The metal die processes give rapid curing, which results in high-volume production. The reinforcer is pulled through an unsaturated resin bath and

then through a heated metal die in the pultrusion process. This process can be adapted for the manufacture of parts with uniform cross sections.

The use of dicyclopentadiene in the polyester backbone improves surfaces and high temperature performance. Thermoplastic unsaturated polyester and unsaturated polyester / polyurethane interpenetrating polymer networks are some recent developments that have led to improved properties.

Unsaturated polyester resins are finding competition from vinyl esters, which are primarily addition products of methacrylic acid and an epoxy resin, diluted with styrene monomer. Vinyl esters have excellent corrosion resistance, and grades with improved flammability resistance and solvent resistance are available.

UP Resins can be made very flame retardant and chemically resistant they also give excellent weatherability. Dimensional stability and rigidity is very good. Moreover, they can be easily reinforced with fibres of various types as part of the moulding stage rather than having to use pre-blended reinforcing agents.

These materials lend themselves to low volume applications with simple tooling, by use of hand lay-up methods of fabrication, or for mass production using injection moulding.

3.2. Selection of the Curing Agent

Unsaturated polyester resins are very versatile materials. At room temperature, the liquid resins are stable for months or even years but can be triggered to cure by a peroxide catalyst.

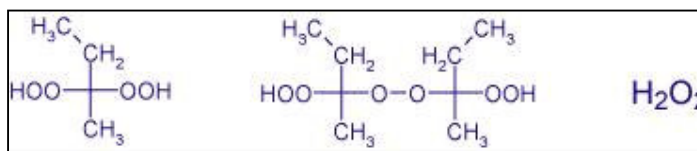


Figure 3.1 Chemical composition of MEKP (Unsaturated Polyester Promoters Web Site)

In unsaturated polyester resin manufacture, the molten polyester is thinned by the cross linking monomer and inhibitor after a condensation reaction to a suitable end-point. This is followed by blending with suitable additives. Unsaturated polyesters can be cross-linked at room or elevated temperatures. For room-temperature curing, a

combination of peroxide and promoter is used; the most common system is a cobalt naphthenate promoter and methyl ethyl ketone peroxide. Cumene hydroperoxide, t-butyl perbenzoate, and t-butyl peroctoate are some of the catalysts used at elevated temperatures. Unsaturated polyesters are used with reinforcers, most notably, glass fiber, but are also used without reinforcers.

Methyl Ethyl Ketone Peroxide (MEKP) named as Luperox K10 is selected and the chemical structure of MEKP is given in Figure3.1. In addition, properties of MEKP are summarized in Appendix A-2.

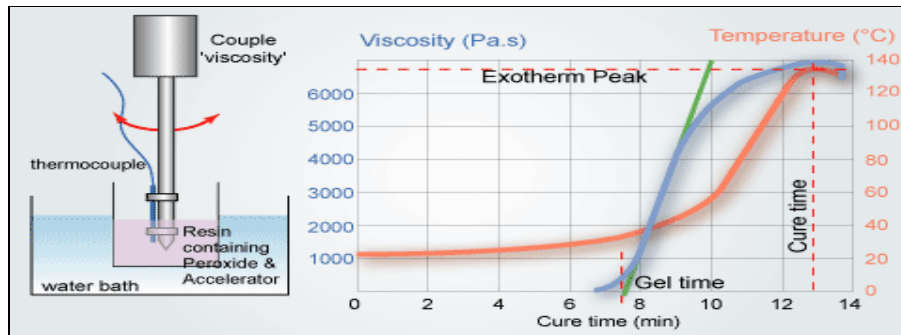


Figure 3.2 Cure performance measurement system (Unsaturated Polyester Promoters Web Site)

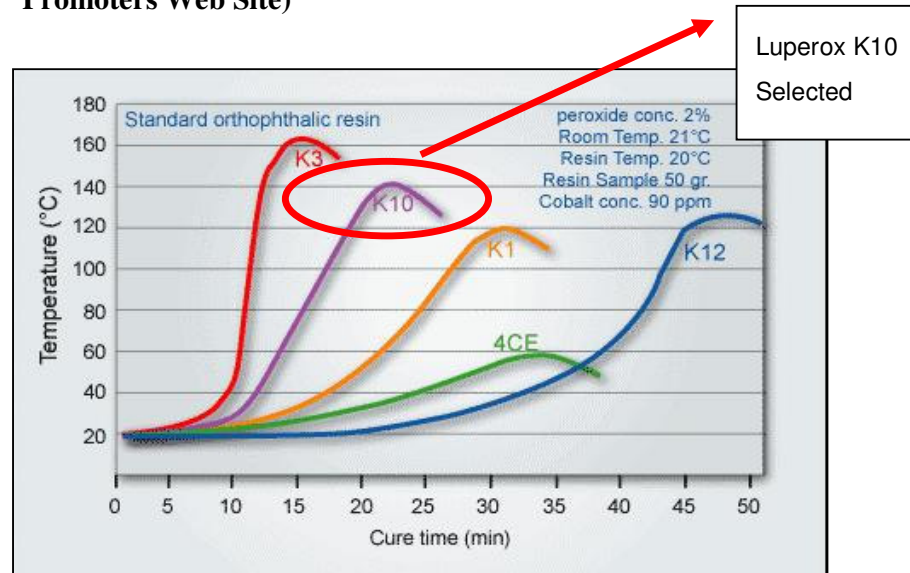


Figure 3.3 Exotherm curves of various ketone peroxides (Unsaturated Polyester Promoters Web Site)

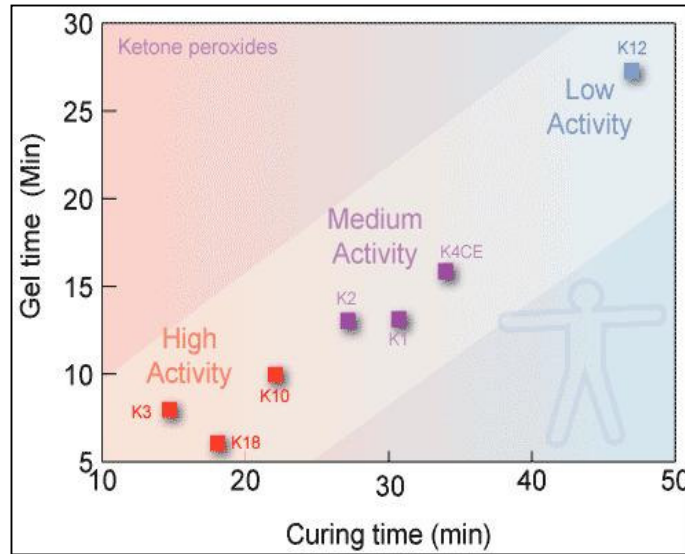


Figure 3.4 Gel and cure time of various ketone peroxides (**Unsaturated Polyester Promoters Web Site**)

3.3. Selection of the Filler

In order to perform the mechanical tests in variety of different fillers and mixing ratios (filler-resin ratio) three different filler is defined:

- Used die sand
- Unused die sand
- BaSO_4

While die sand is more economical, BaSO_4 has the ability to reach higher density values. Chemical composition of the both used and unused die sands are given in Figure 3.5.

Unused Die Sand

Si	76.232 %	(0.256)	Quan-FP	SiKa	0.781
K	13.932 %	(0.042)	Quan-FP	K Ka	1.071
Al	4.007 %	(0.334)	Quan-FP	AlKa	0.007
Fe	1.987 %	(0.016)	Quan-FP	FeKa	5.356
Ca	1.972 %	(0.017)	Quan-FP	CaKa	0.208
S	1.695 %	(0.032)	Quan-FP	S Ka	0.057
Sr	0.103 %	(0.003)	Quan-FP	SrKa	1.903
Rb	0.072 %	(0.003)	Quan-FP	RbKa	1.184

Used Die Sand

GeKa 9.81 0.091					

Quantitative Result					

Analyte	Result	(Std.Dev.)	Proc.-Calc.	Line	Int.(cps/uA)

Si	52.252 %	(0.307)	Quan-FP	SiKa	0.519
Fe	22.540 %	(0.045)	Quan-FP	FeKa	79.862
Al	9.830 %	(0.428)	Quan-FP	AlKa	0.016
Ca	6.810 %	(0.026)	Quan-FP	CaKa	1.319
K	2.961 %	(0.023)	Quan-FP	K Ka	0.364
Ti	2.829 %	(0.030)	Quan-FP	TiKa	3.472
S	1.561 %	(0.032)	Quan-FP	S Ka	0.081
Zr	0.358 %	(0.004)	Quan-FP	ZrKa	6.338
Mn	0.302 %	(0.010)	Quan-FP	MnKa	0.827
Sr	0.182 %	(0.003)	Quan-FP	SrKa	2.693
Cr	0.147 %	(0.010)	Quan-FP	CrKa	0.344
Zn	0.092 %	(0.005)	Quan-FP	ZnKa	0.505
V	0.070 %	(0.013)	Quan-FP	V Ka	0.123
Ge	0.067 %	(0.004)	Quan-FP	GeKa	0.506

Figure 3.5 Chemical Composition of the die sand

3.4. Selection of the Mould

St 35 is used as the mould material; opening through the diagonal, which makes getting the specimen out of the mould easier shown in Figure 3.6. Cube model with 50x50x50 dimesions is selected as a result of being an appropriate geometric model of the upper counter-weight.

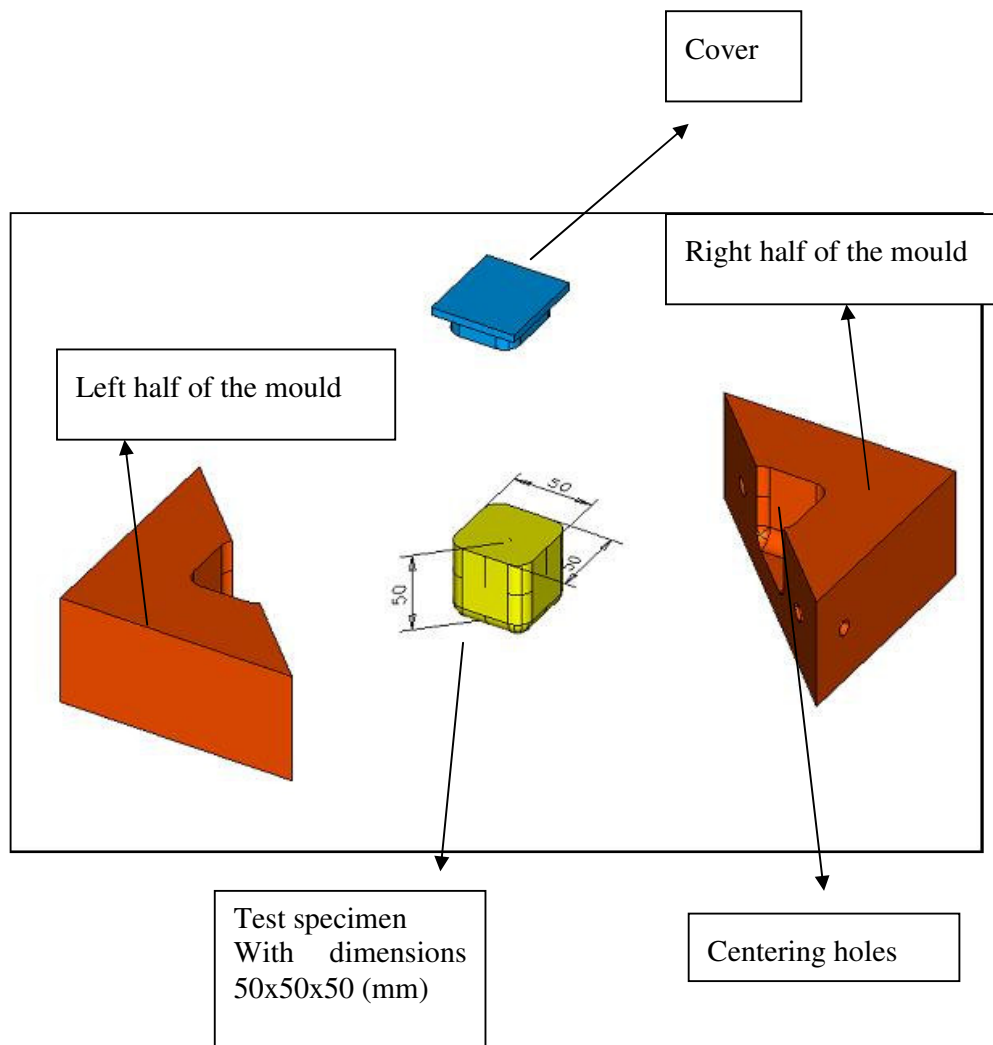


Figure 3.6 Mould layout

3.5. Selection of the Working Area

Working area is made narrower after preparing samples of the whole mixing volume ratios rating as 0:100, 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20, 90:10, 100:0.

3.6. Determination of Physical and Mechanical Properties

3.6.1. Density Measurement Tests:

Theoretical Density of each mixture is calculated given below

$$\text{Density} = (\text{Total volume}) / (\text{Total mass}) \quad [1]$$

A, B are the percentages of the filler and the resin in the total mass of the mixture

$$\text{Total volume} = A / d_1 + B / d_2 \quad [2]$$

$$\text{Total mass} = A + B = 100 \quad [3]$$

$$A / B = \text{Mixing Ratio} \quad [4]$$

Activators, named Cobalt Naphthenate and Methyl Ethyl Ketone Peroxide are neglected according to their consumption ratios. Theoretical density calculations of the different mixing ratio are given in Appendix B.

Besides, experimental density values are measured and given in Appendix C. Polyester filled with BaSO_4 has the greatest density values, which brings the advantage of volume reduction in the component. On the other hand, polyester filled with used die sand has the lowest values.

According to the voids in the specimen, experimental density values are less than the theoretically calculated values.

3.6.2. Compression Tests:

Specimens are prepared in the dimensions 15x15x30 mm and compressed in the test unit shown in Figure 3.7.



Figure 3.7 Compression test unit

Compression test specimen geometry and size for cement is explained as a cylinder with 6 mm diameter and 12 mm height by ISO 5833 testing standard. As it is mentioned above in mould selection section, cube model with 50x50x50 dimensions is selected as a result of being an appropriate geometric model of the upper counter-weight. As a consequence of the problems occurred according to the capacity of the compression test unit, dimensions of the specimen is decreased. In Appendix D, mixing values for all components include are given by weight for all test specimens.



Figure 3.8 Compression test results

Force and displacement values of compression test specimens shown in Appendix E-1, and graphed in Appendix E-2.

Standart deviation in each sub-group and for overall values are calculated discussed by One Way Anova Analysis in Minitab programme (Figure 3.9) and the results are plotted by Box Plot (Figure 3.10).

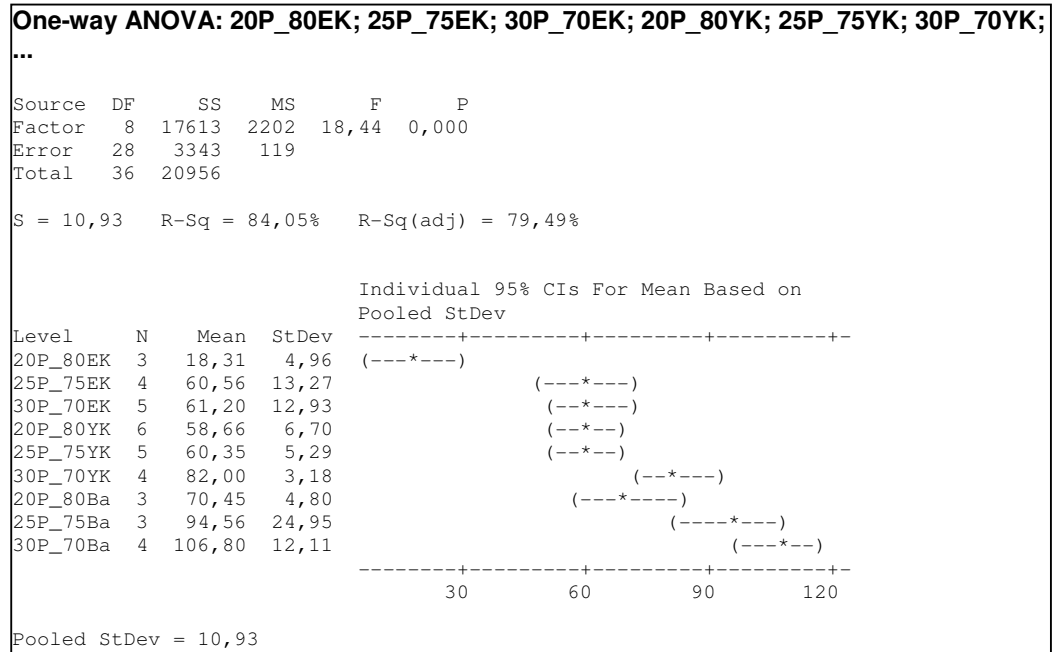


Figure 3.9 One way anova analysis

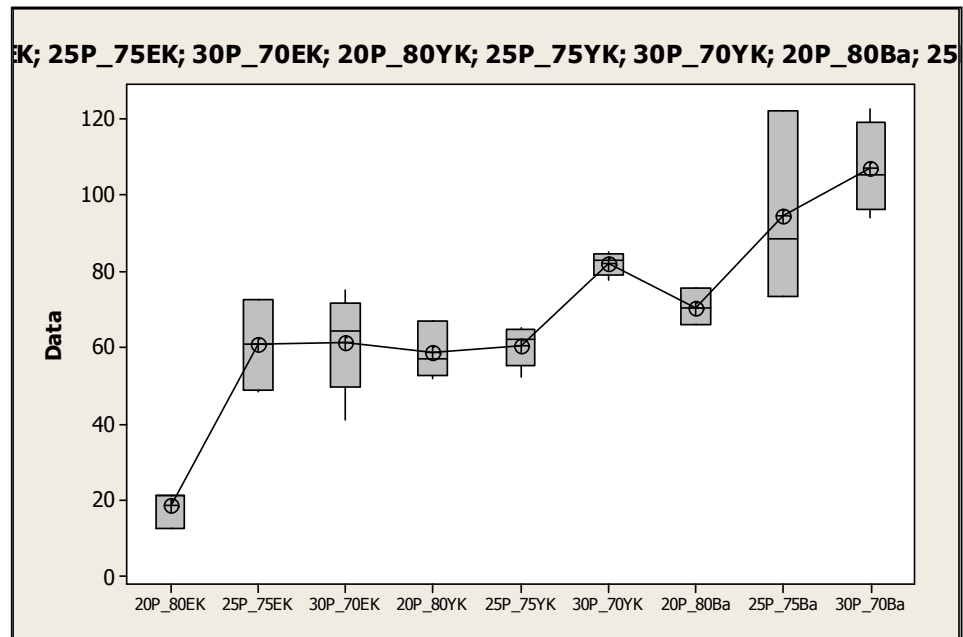


Figure 3.10 Box plot analysis

Reliability of the compression test results are also. The test results have the power of 90%.

Alpha = 0,05

Assumed standard deviation = 10,98

Number of Levels = 9

Table 3.1. Confidence level of compression test results

Sample Size	Power	SS Means	Maximum Difference
37	0,80	49,6710	9,9670
37	0,85	55,4500	10,5309
37	0,90	63,0988	11,2338

4. CONCLUSION

In this study, physical and mechanical properties of the possible polyester and promoting agents and three different types of filler mixture were investigated.

Better results were obtained with the formulations consisting of both 25% resin and 75% filler. Among these formulations the best performance was observed in the formulation containing 25% Polyester and 75% BaSO₄. This formulation was recorded to give outstanding results in both in density measurements and compression tests. Density test results may be explained by the higher density of BaSO₄ comparing with both used and unused die sand.

Results of the mechanical tests showed that the compression properties of the formulations improve according to the polyester content. Moreover, compression test results of BaSO₄ may be explained by the powerful cross-links between the BaSO₄ and Polyester.

Therefore, after the evaluation of mechanical tests and density measurement results, the formulation 25% Polyester and 75% BaSO₄ seemed to be promising to be used in a composite counter-weight design.

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APPENDIX A-1



CAMELYAF
POLYESTER / GEL-COAT




ORTOFTALİK POLYESTER GENEL AMAÇLI CTP UYGULAMALARI

CE 92 N8

Genel amaçlı CTP uygulamaları için geliştirilmiş, orta reaktiviteli, ortohtalik polyester reçinedir.

Sağladığı Faydalar:

- Uygun viskozitesi sayesinde cam elyafını çabuk ve kolay ıslatır.
- Yüksek mekanik dayanımı sağlar.

Sıvı CE 92 N8 Özellikleri:

Özellikler	Birim	Spesifikasyon Değerleri
Görünüm		Berrak
Viskozite	cps	400±60
Asit Sayısı	mgKOH/g	Max.25
Katı Madde Miktarı	%	Min.58
Jelleşme Süresi (25°C)*	dak.	8±2
Egzoterm Pık (25°C)	°C	180±20
Stabilite	ay	4

(*) Jelleşme süresi ve "Egzoterm Pık" tayini 50 mm çapında bir beherglassa konan 100 g reçineye 25°C'de % 0.25 oranında % 6'lık Kobalt Naftanat ve % 2 oranında % 50 aktif Metil Etil Keton Peroksit ilave edilmesinden sonra yapılır.

Sertleşmiş CE 92 N8 Özellikleri:

Özellikler	Birim	Spesifikasyon Değerleri
Sertlik	Barcol	Min.42
Eğilme Dayanımı	kgf/cm ²	Min.900
Çekme Dayanımı	kgf/cm ²	Min.500

CE 92 N8 ORTOFTALİK POLYESTER ISO 9001: 2000 STANDARDI GEREKLERİNE UYGUN OLARAK ÜRETİLMEKTEDİR. (07.04)

Figure A-1.1 Datasheet of the Polyester resin CE 92 N8 (Ortoftalik Polyester Genel Amaçlı CTP Uygulamaları, Şişecam Web Site)



CAMELYAF
POLYESTER / GEL-COAT



Ambalaj:

CE 92 N8, 18 kg'lık tenekelerde ve 230 kg'lık sac varillerde satılmaktadır. (Tenekeler; 96 cm x120 cm boyutlarında ahşap paletler üzerinde teslim edilir. Bir palette 40 tenekeli CE 92 N8 bulunur.)



Stoklama Koşulları:

CE 92 N8, orijinal ambalajında 20°C sıcaklığın altında ve direkt gün ışığına maruz bırakılmadan, etiketi üzerinde belirtilen son kullanma tarihine kadar stoklanabilir. Stoklama tankları paslanmaz çelik, alüminyum veya CE 266 N12 polyesteri ile yapılmış CTP'den olabilir.



Sipariş Verirken Lütfen Belirtiniz!

- Ürün Kodu
- Ambalaj Cinsi
- Sipariş Miktarı

■ Şirketimizin teknik danışmanlığını üstlenmediği son ürün yapımında, uygulamalardan doğabilecek sorunlardan, belirlenen teknik değerler nedeniyle şirketimiz sorumlu tutulamaz.

■ Ürün nitelikleri, yapılan gelişmelere bağlı olarak değişebilir.

■ Son kullanım amaçlarına göre özel ürün, istek üzerine üretilir.



Xn



F+ (Very Flammable)

BİLGİLER:
R 10 - Akıcıdır.
R 30 - Sıkıştırılmış halde yüksek basınçlıdır.
R 35/36 - Gözleri ve cildi tahriş eder.
Güvenlik Tipleri:
S 10 - Tehlikeli maddelerin temasından kaçınılmalıdır.
S 23 - Sıkıştırılmış gazların kullanımı için tehlikeye atılmamalıdır.
S 24 - Sıkıştırılmış gazların kullanımı için tehlikeye atılmamalıdır.
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ŞİŞECAM

Figure A-1.1 Datasheet of the Polyester resin CE 92 N8 (Ortoftalik Polyester Genel Amaçlı CTP Uygulamaları, Şişecam Web Site)

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APPENDIX A-2

Table A-2.1 Properties of MEKP (Unsaturated Polyester Promoters Web Site)

Methyl ethyl ketone peroxide (MEKP)					
Luperox K1	Medium activity MEKP a standard general purpose hardener for a wide variety of ambient temperature application. Low hydrogen peroxide content makes K1 ideal for use in gel coats Luperox K1 is the Luperox recommended for gel coats.	Phthalate	9.2	Hand Lay-up Spray-up Resin Transfer moulding Vacuum moulding Centrifugal casting Filament winding Panels & sheets Casting Varnishes Gel coats Concrete & marble Putties	
Luperox K10	High activity MEKP - gives fast gel and cure time for a wide variety of ortho and isophthalic resin systems.	Phthalate	9.9	Hand Lay-up Spray-up Centrifugal casting Panels & sheets Varnishes	
Luperox K18	Ultra high activity MEKP - extremely short gel time. Recommended for button sheets, continuous sheet production and varnishes.	Phthalate	9.9	Varnishes Buttons	
Luperox K12	1. Low activity MEKP which gives long gel time in a wide variety of ortho-and isophthalic resin systems. Particularly suitable during the warm season and for very large moulded pieces. 2. High activity MEKP for use in a wide variety of vinyl ester resins to get no foaming effect.	Phthalate	8.5	Hand Lay-up Centrifugal casting Filament winding Casting Vinyl ester & bisphenol resins	

APPENDIX B

Table B.1 Theoretical Density Values

Density(gr/cm3)	Material
2,66	Unused Die Sand
2,2	Polyester

Components	Unused Die Sand-Polyester Mixing Ratios											
Polyester	100	90	80	70	60	50	40	30	25	20	10	0
Unused Die Sand	0	10	20	30	40	50	60	70	75	80	90	100
	45,45	40,91	36,36	31,82	27,27	22,73	18,18	13,64	11,36	9,09	4,55	0,00
	0,00	3,76	7,52	11,28	15,04	18,80	22,56	26,32	28,20	30,08	33,83	37,59
Total volume	45,45	44,67	43,88	43,10	42,31	41,52	40,74	39,95	39,56	39,17	38,38	37,59
Total mass	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Densitiy	2,20	2,24	2,28	2,32	2,36	2,41	2,45	2,50	2,53	2,55	2,61	2,66

APPENDIX B

Table B.1 Theoretical Density Values (Continuing)

Density(gr/cm3)	Material
4,5	BaSO4
2,2	Polyester

Components	BaSO4-Polyester Mixing Ratios											
Polyester	100	90	80	70	60	50	40	30	25	20	10	0
BaSO4	0	10	20	30	40	50	60	70	75	80	90	100
	45,45	40,91	36,36	31,82	27,27	22,73	18,18	13,64	11,36	9,09	4,55	0,00
	0,00	2,22	4,44	6,67	8,89	11,11	13,33	15,56	16,67	17,78	20,00	22,22
Total volume	45,45	43,13	40,81	38,48	36,16	33,84	31,52	29,19	28,03	26,87	24,55	22,22
Total mass	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Densitiy	2,20	2,32	2,45	2,60	2,77	2,96	3,17	3,43	3,57	3,72	4,07	4,50

APPENDIX B

Table B.1 Theoretical Density Values (Continuing)

Density (gr/cm3)	Material
2,63	Used Die Sand
2,2	Polyester

Components	Used Die Sand-Polyester Mixing Ratios											
Polyester	100	90	80	70	60	50	40	30	25	20	10	0
Used Die sand	0	10	20	30	40	50	60	70	75	80	90	100
	45,45	40,91	36,36	31,82	27,27	22,73	18,18	13,64	11,36	9,09	4,55	0,00
	0,00	3,80	7,60	11,41	15,21	19,01	22,81	26,62	28,52	30,42	34,22	38,02
Total volume	45,45	44,71	43,97	43,23	42,48	41,74	41,00	40,25	39,88	39,51	38,77	38,02
Total mass	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Densitiy	2,20	2,24	2,27	2,31	2,35	2,40	2,44	2,48	2,51	2,53	2,58	2,63

APPENDIX C

Table C.1 Experimental Density Values of the Specimens

% 20 Polyester+% 80 Used Die Sand	Theoretical Density (g/cm3)	Experimental Density (g/cm3)
Specimen: 1	2,53	2,23
Specimen: 2		2,21
Specimen: 3		2,30

% 20 Polyester+% 80 Unused Die Sand	Theoretical Density (g/cm3)	Experimental Density (g/cm3)
Specimen: 1	2,55	2,04
Specimen: 2		2,05
Specimen: 3		2,08

% 20 Polyester+% 80 BaSO4	Theoretical Density (g/cm3)	Experimental Density (g/cm3)
Specimen: 1	3,72	2,77
Specimen: 2		2,76
Specimen: 3		2,83

Table C.1 Experimental Density Values of the Specimens (Continuing)

% 25 Polyester+ % 75 Used Die Sand	Theoretical Density (g/cm3)	Experimental Density (g/cm3)
Specimen: 1	2,51	1,89
Specimen: 2		1,95
Specimen: 3		1,99

% 25 Polyester+ % 75 Unused Die Sand	Theoretical Density (g/cm3)	Experimental Density (g/cm3)
Specimen: 1	2,53	1,99
Specimen: 2		1,96
Specimen: 3		1,93

% 25 Polyester+ % 75 BaSO4	Theoretical Density (g/cm3)	Experimental Density (g/cm3)
Specimen: 1	3,57	2,65
Specimen: 2		2,70
Specimen: 3		2,57

Table C.1 Experimental Density Values of the Specimens (Continuing)

% 30 Polyester+% 70 Used Die Sand	Theoretical Density (g/cm ³)	Experimental Density (g/cm ³)
Specimen: 1	2,48	1,78
Specimen: 2		1,79
Specimen: 3		1,81

% 30 Polyester+% 70 Unused Die Sand	Theoretical Density (g/cm ³)	Experimental Density (g/cm ³)
Specimen: 1	2,5	1,89
Specimen: 2		1,88
Specimen: 3		1,90

% 30 Polyester+% 70 BaSO₄	Theoretical Density (g/cm ³)	Experimental Density (g/cm ³)
Specimen: 1	3,43	2,38
Specimen: 2		2,28
Specimen: 3		2,40

APPENDIX D

Table D.1 Preparation of Compression Test Samples

Preparation of Test Specimen				
	% 25+ % 75			
% 25	Weight of the components (g)			
Polyester+ % 75 Used Die Sand	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	Used Die Sand
Theoretical values (g)	75	0,187	1,5	225
Specimen: 1	75,07	0,18	1,5	225,07
Specimen: 2	75,23	0,19	1,52	225,02
Specimen: 3	74,99	0,18	1,54	225,07
Repeat of Specimen: 3	75,09	0,21	1,5	225,04

% 25	Weight of the components (g)			
Polyester+ % 75 Unused Die Sand	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	Unused Die Sand
Theoretical values (g)	75	0,187	1,5	225
Specimen: 1	74,99	0,19	1,52	224,92
Specimen: 2	75,04	0,19	1,51	225,03
Specimen: 3	75,01	0,185	1,51	225,05

% 25	Weight of the components (g)			
Polyester+ % 75 BaSO4	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	BaSO4
Theoretical values (g)	100	0,25	2	300
Specimen: 1	100,08	0,25	2,07	300,01
Specimen: 2	99,9	0,24	2	300,07
Specimen: 3	100,02	0,25	2	300,01

Table D.1 Preparation of Compression Test Samples (Continuing)

		% 20+% 80			
% 20	Weight of the components (g)				
Polyester+% 80					
Used Die Sand	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	Used Die Sand	
Theoretical values (g)	60	0,15	1,2	240	
Specimen: 1	59,98	0,15	1,22	240,02	
Specimen: 2	60,01	0,14	1,21	240,02	
Specimen: 3	60,06	0,15	1,19	240,01	
Repeat of Specimen: 3	60,03	0,16	1,23	240,59	

% 20 Polyester+% 80 Unused Die Sand	Weight of the components (g)			
	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	Unused Die Sand
Theoretical values (g)	60	0,15	1,2	240
Specimen: 1	60,07	0,14	1,22	240,09
Specimen: 2	59,9	0,16	1,19	240,03
Specimen: 3	60,01	0,16	1,19	240,05

% 20 Polyester+% 80 BaSO4	Weight of the components (g)			
	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	BaSO4
Theoretical values (g)	80	0,2	1,6	320
Specimen: 1	80,01	0,19	1,6	320,05
Specimen: 2	79,77	0,21	1,59	319,86
Specimen: 3	80,01	0,22	1,64	320,08

Table D.1 Preparation of Compression Test Samples (Continuing)

		% 30+% 70			
% 30 Polyester+% 70 Used Die Sand	Weight of the components (g)				
	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	Used Die Sand	
Theoretical values (g)	90	0,225	1,8	210	
Specimen: 1	89,97	0,22	1,82	209,9	
Specimen: 2	89,95	0,22	1,79	210,07	
Repeat of Specimen: 2	89,99	0,24	1,79	209,8	
Specimen: 3	90,15	0,23	1,8	210,05	

% 30 Polyester+ % 70 Unused Die Sand	Weight of the components (g)			
	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	Unused Die Sand
Theoretical values (g)	90	0,225	1,8	210
Specimen: 1	89,97	0,22	1,79	209,94
Specimen: 2	90,02	0,23	1,81	210,03
Specimen: 3	90,02	0,23	1,8	210,01

% 30 Polyester+ % 70 BaSO4	Weight of the components (g)			
	Polyester	Cobalt Naphthenate	Methyl Ethyl Ketone Peroxide	BaSO4
Theoretical values (g)	120	0,3	2,4	280
Specimen: 1	119,93	0,34	2,4	279,46
Specimen: 2	119,97	0,29	2,39	280,09
Specimen: 3	119,92	0,29	2,4	280

APPENDIX E-1

Table E-1.1 Compression Strenghts of Specimens

20% Polyester 80% Used Sand	25% Polyester 75% Used Sand	30% Polyester 70% Used Sand
21,17	71,69	64,09
21,18	72,39	57,84
12,59	48,44	40,93
	49,73	68,13
		74,99
20% Polyester 80% Unused Sand	25% Polyester 75% Unused Sand	30% Polyester 70% Unused Sand
55,4	52,06	77,5
52,69	61,92	83,16
58,62	58,52	84,92
66,58	63,97	82,43
51,77	65,28	
66,92		
20% Polyester 80% BaSO4	25% Polyester 75% BaSO4	30% Polyester 70% BaSO4
65,85	122,08	122,33
70,09	73,43	94,19
75,42	88,18	101,13
		109,54

APPENDIX E-2 Compression Test Graphs

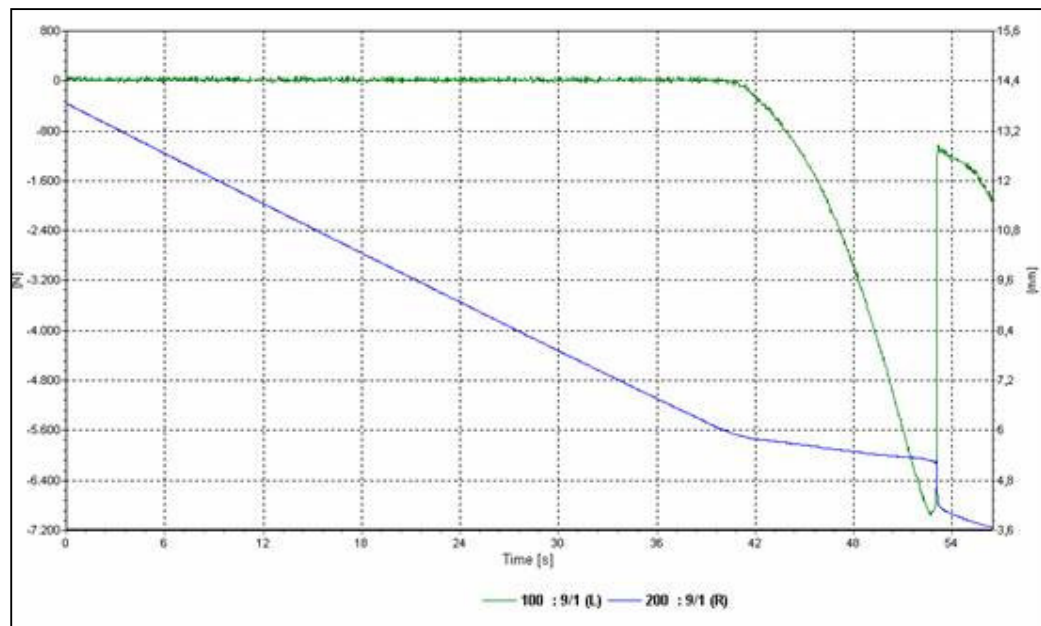


Figure E-2.1 Event 1: 20% Polyester 80% Used Sand

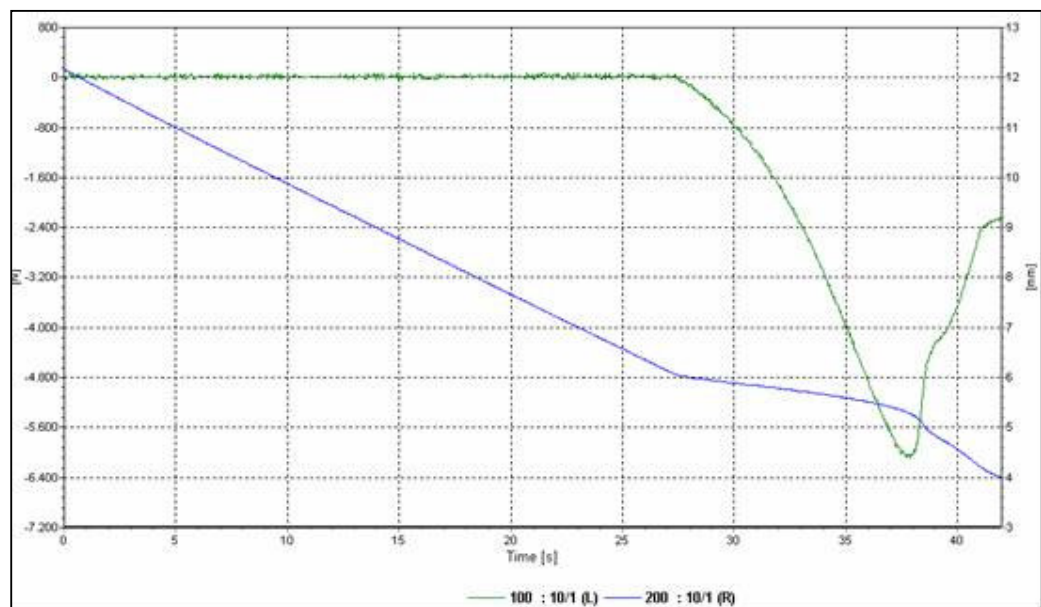


Figure E-2.2 Event 2: 20% Polyester 80% Used Sand

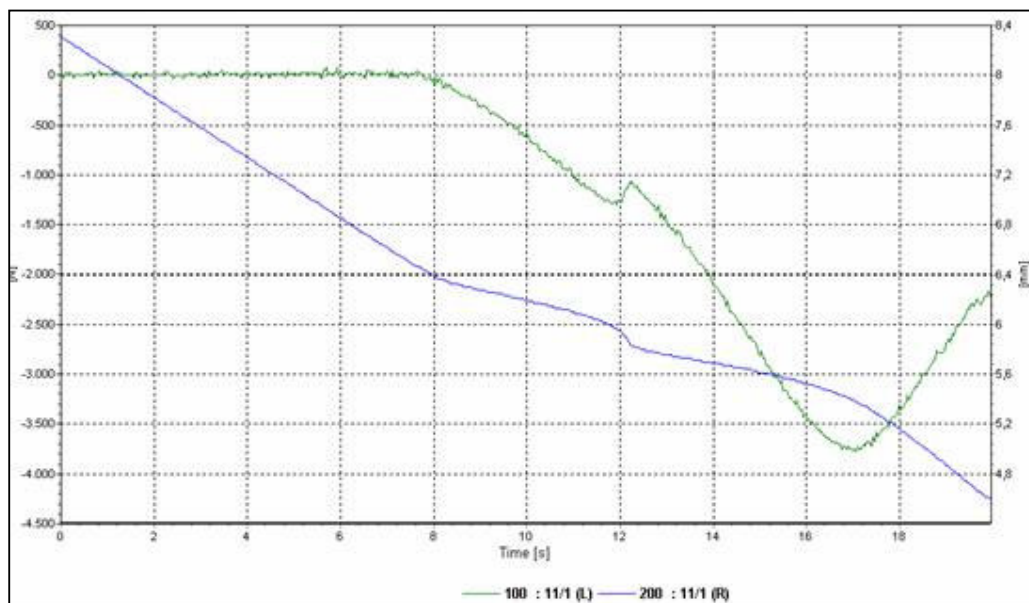


Figure E-2.3 Event 3: 20% Polyester 80% Used Sand

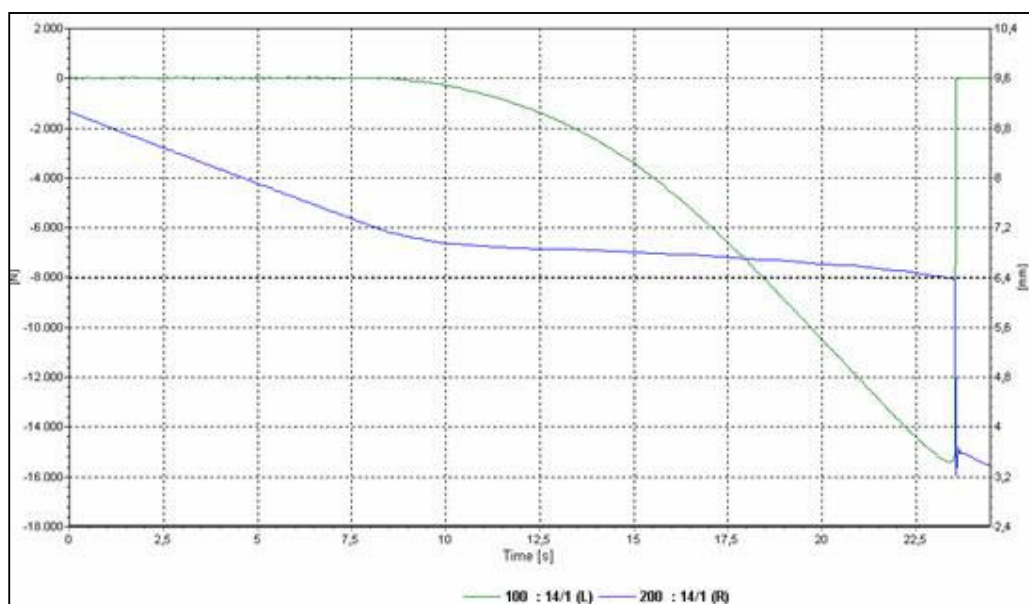


Figure E-2.4 Event 4: 25% Polyester 75% Used Sand

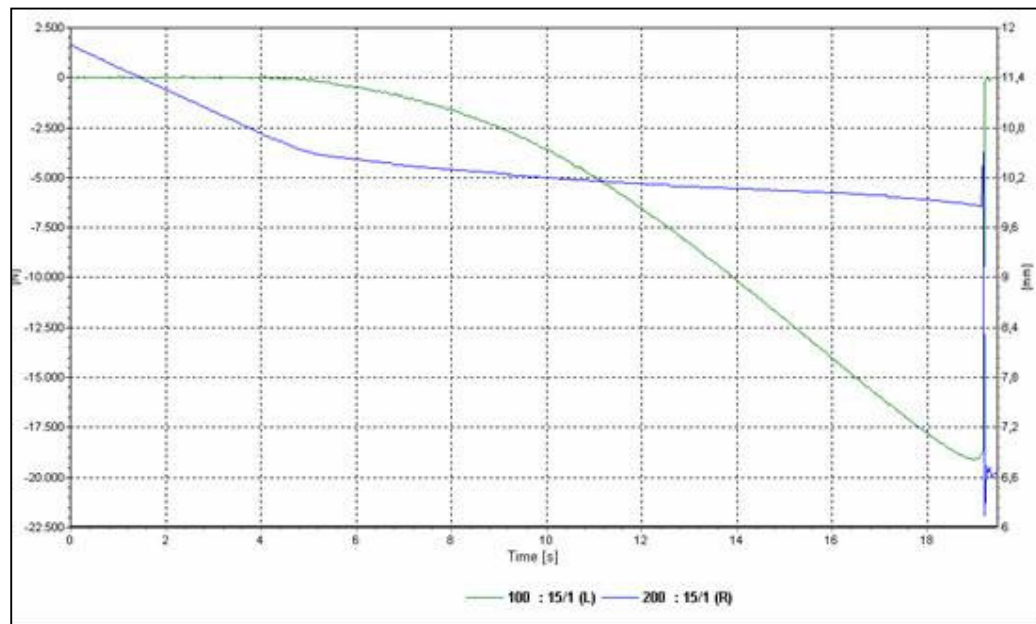


Figure E-2.5 Event 5: 25% Polyester 75% Used Sand

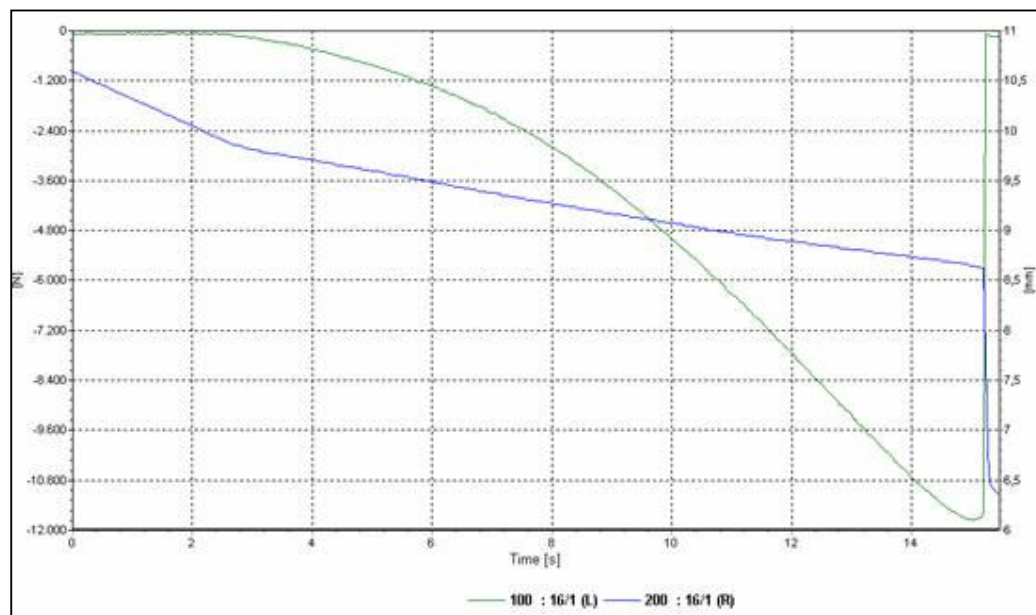


Figure E-2.6 Event 6: 25% Polyester 75% Used Sand

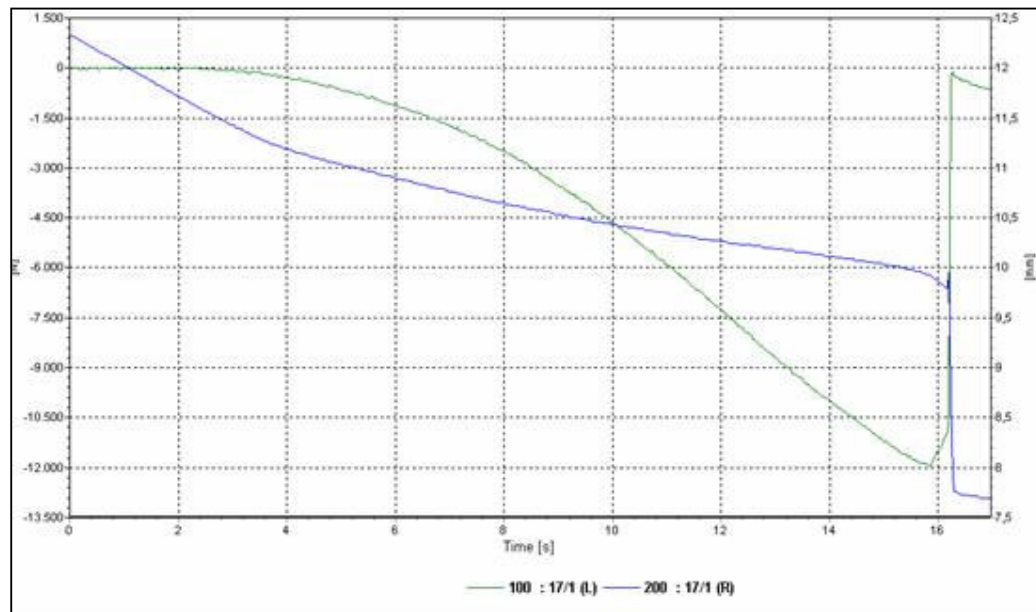


Figure E-2.7 Event 7: 25% Polyester 75% Used Sand

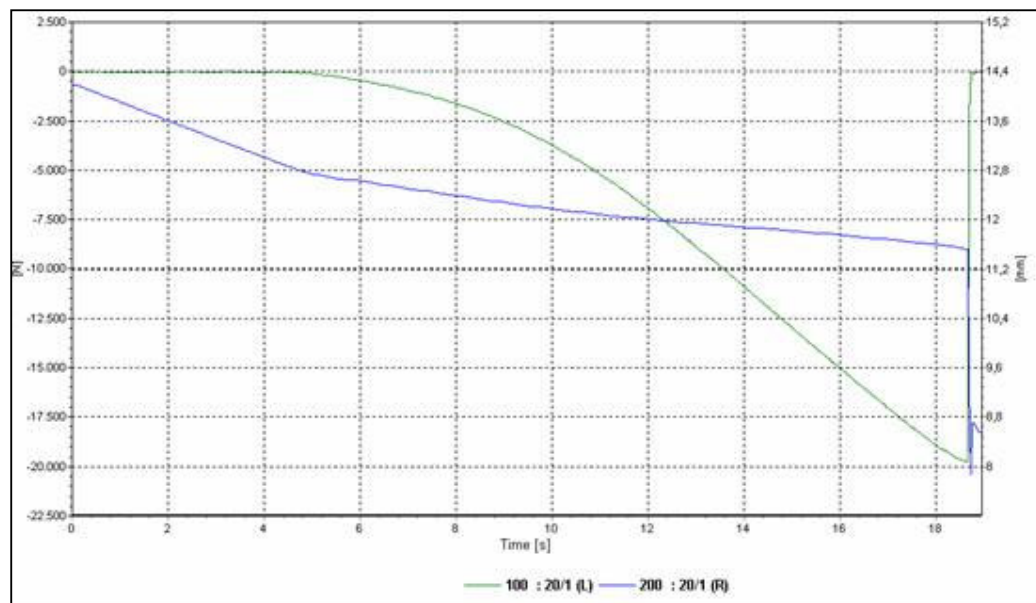


Figure E-2.8 Event 8: 30% Polyester 70% Used Sand

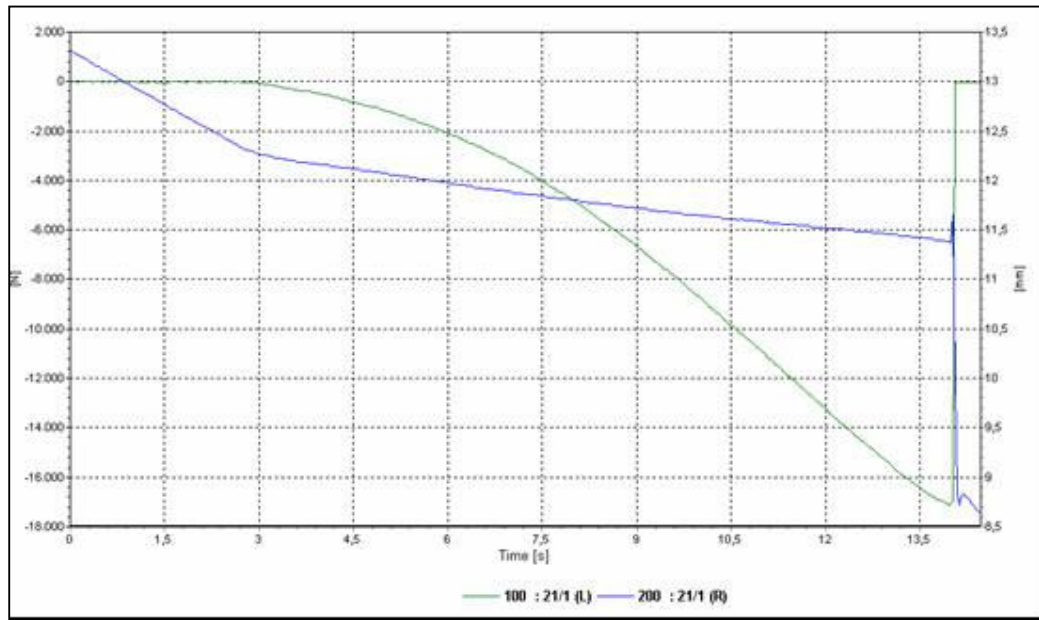


Figure E-2.9 Event 9: 30% Polyester 70% Used Sand

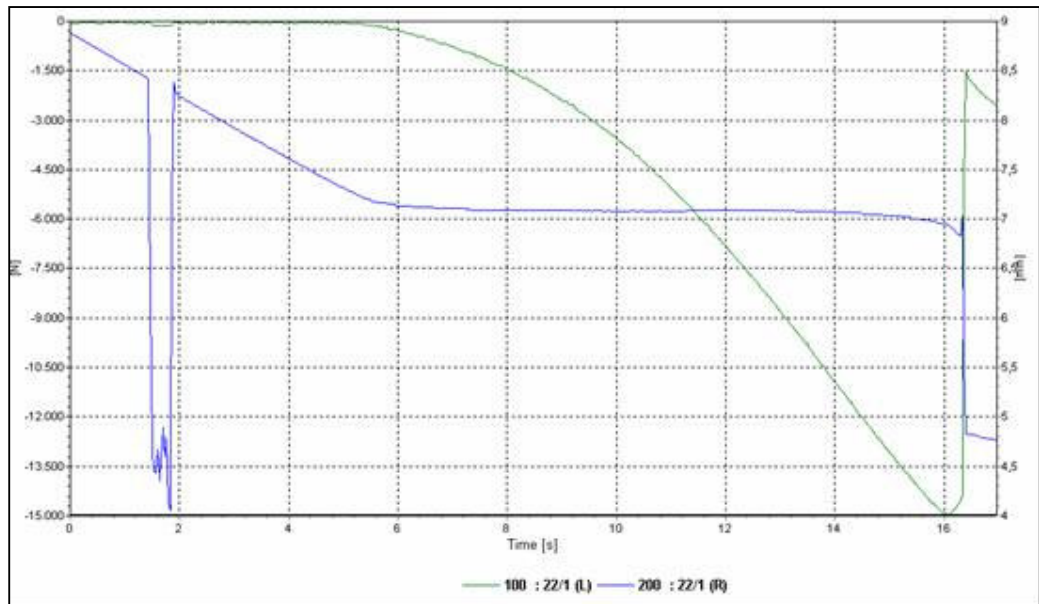


Figure E-2.10 Event 10: 30% Polyester 70% Used Sand

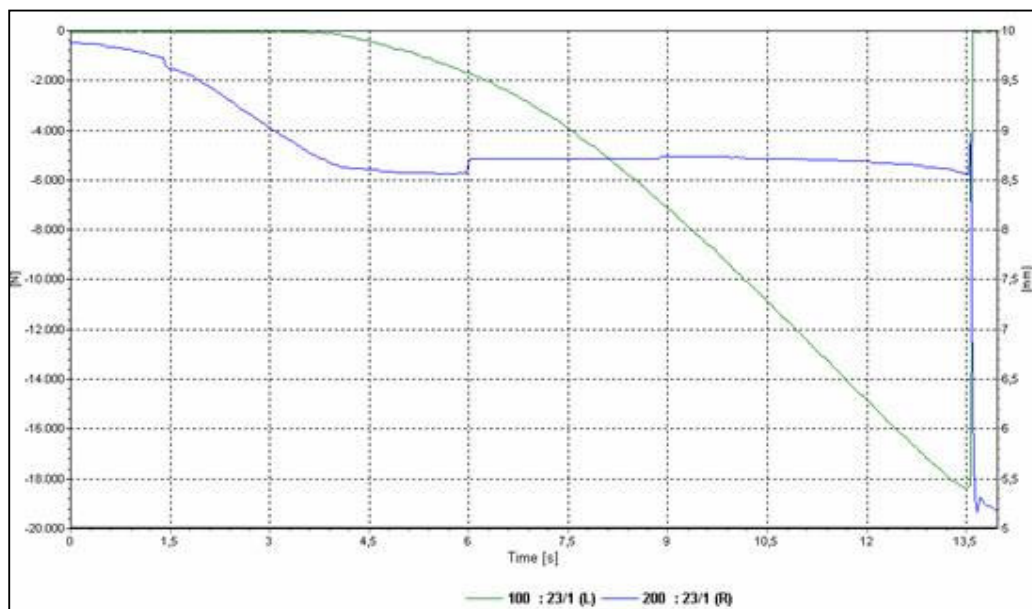


Figure E-2.11 Event 11: 30% Polyester 70% Used Sand

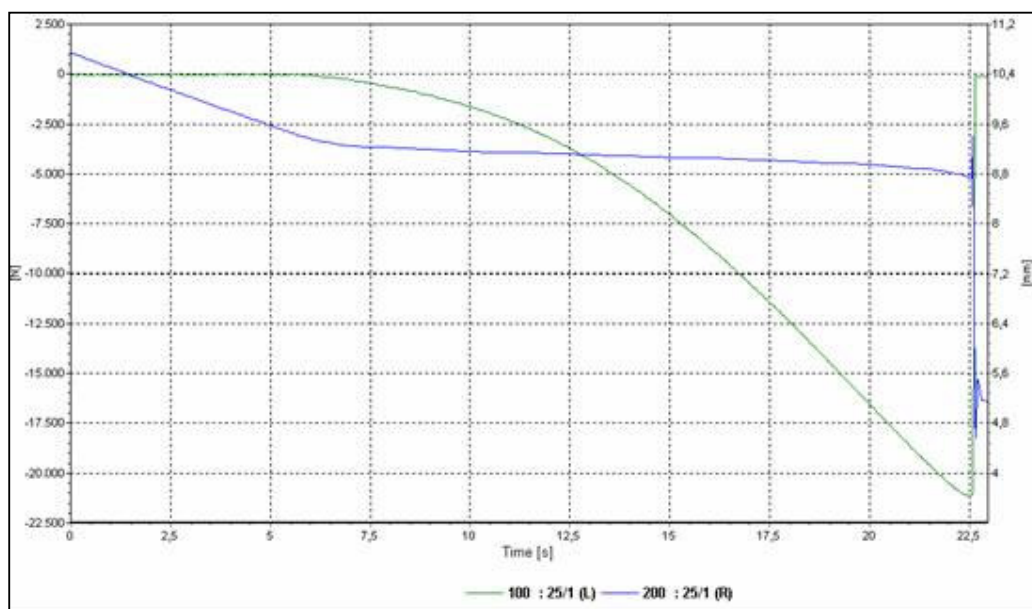


Figure E-2.12 Event 12: 30% Polyester 70% Used Sand

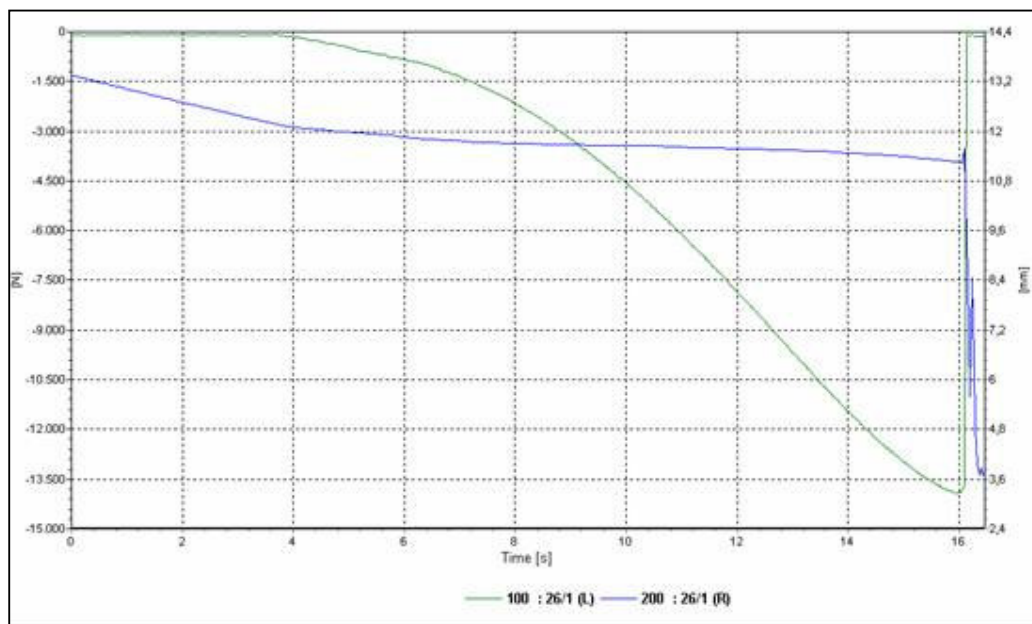


Figure E-2.13 Event 13: 20% Polyester 80% Unused Sand

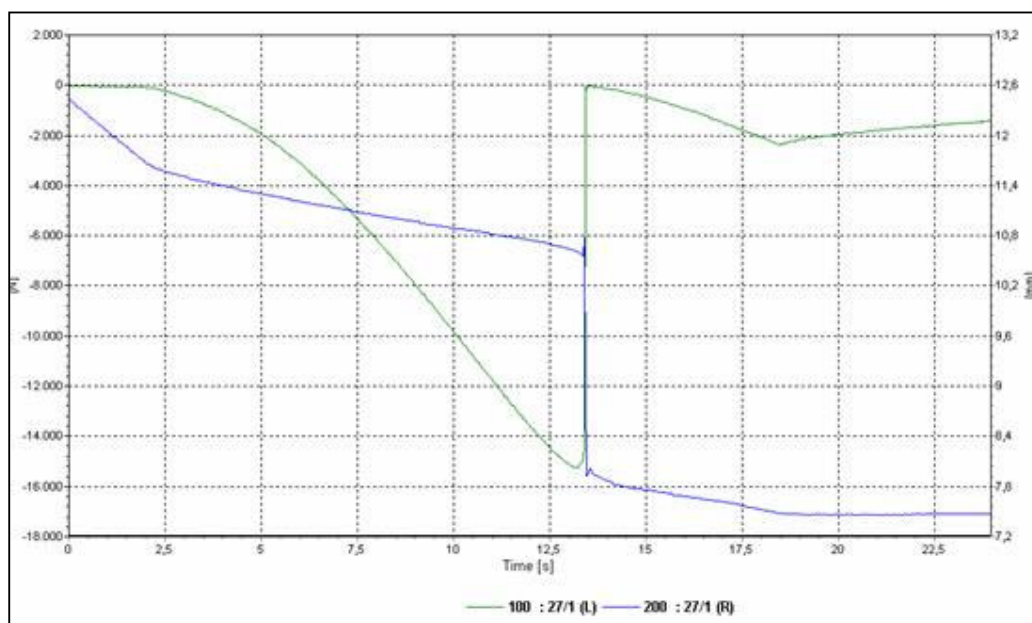


Figure E-2.14 Event 14: 20% Polyester 80% Unused Sand

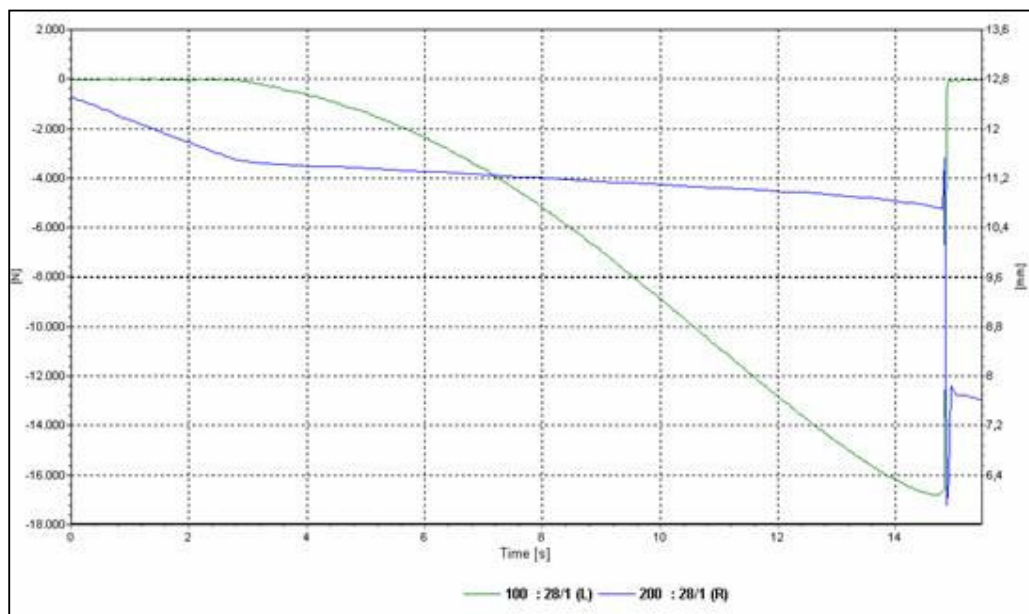


Figure E-2.15 Event 15: 20% Polyester 80% Unused Sand

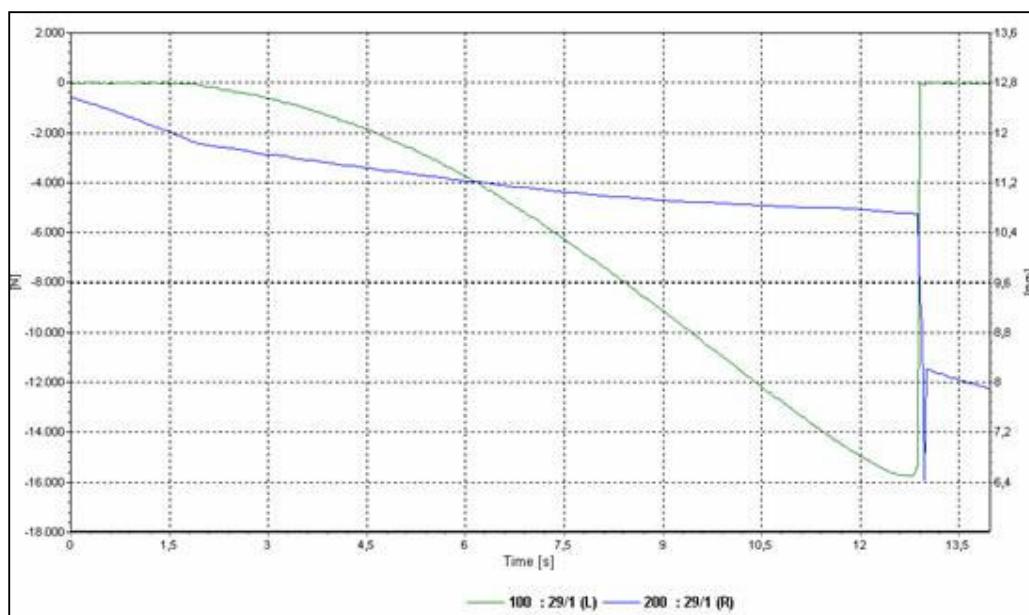


Figure E-2.16 Event 16: 20% Polyester 80% Unused Sand

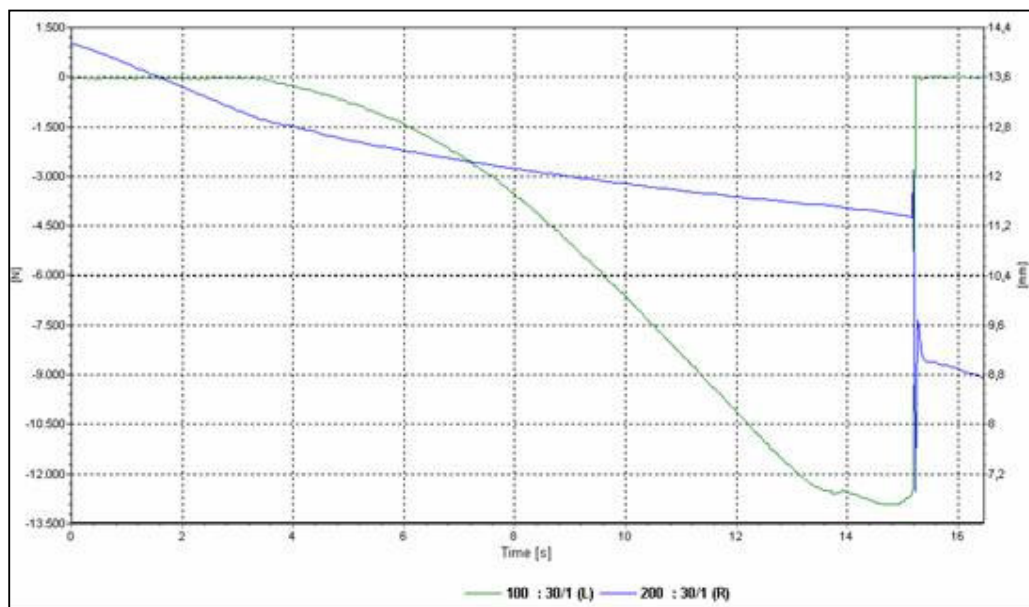


Figure E-2.17 Event 17: 20% Polyester 80% Unused Sand

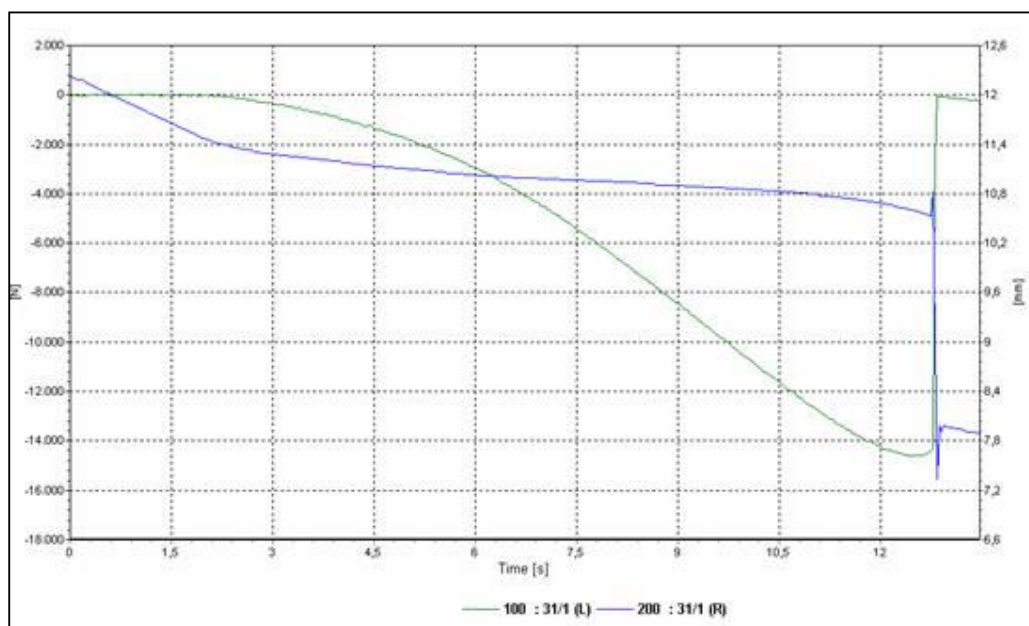


Figure E-2.18 Event 18: 20% Polyester 80% Unused Sand

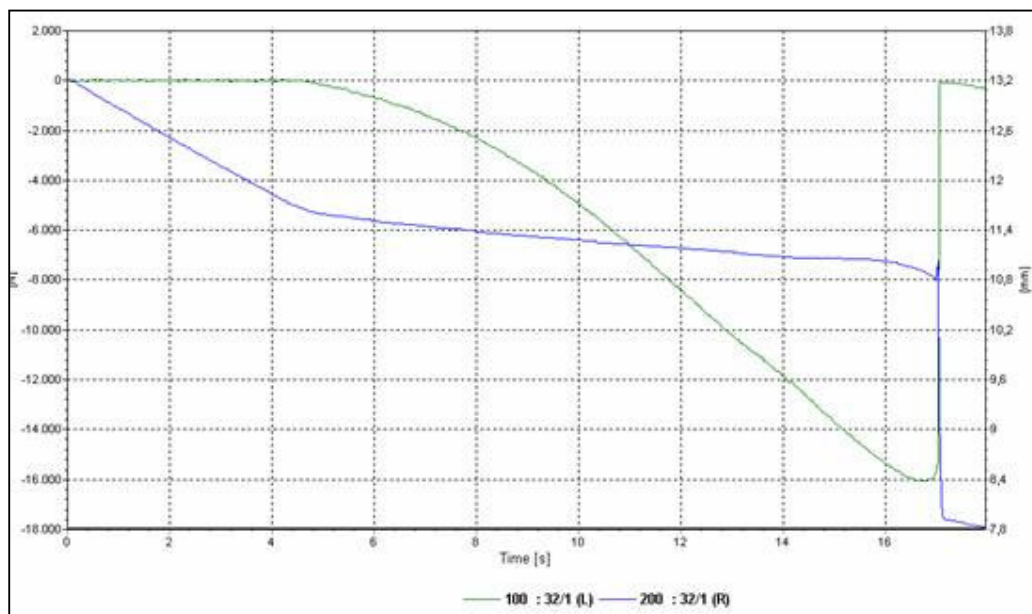


Figure E-2.19 Event 19: 25% Polyester 75% Unused Sand

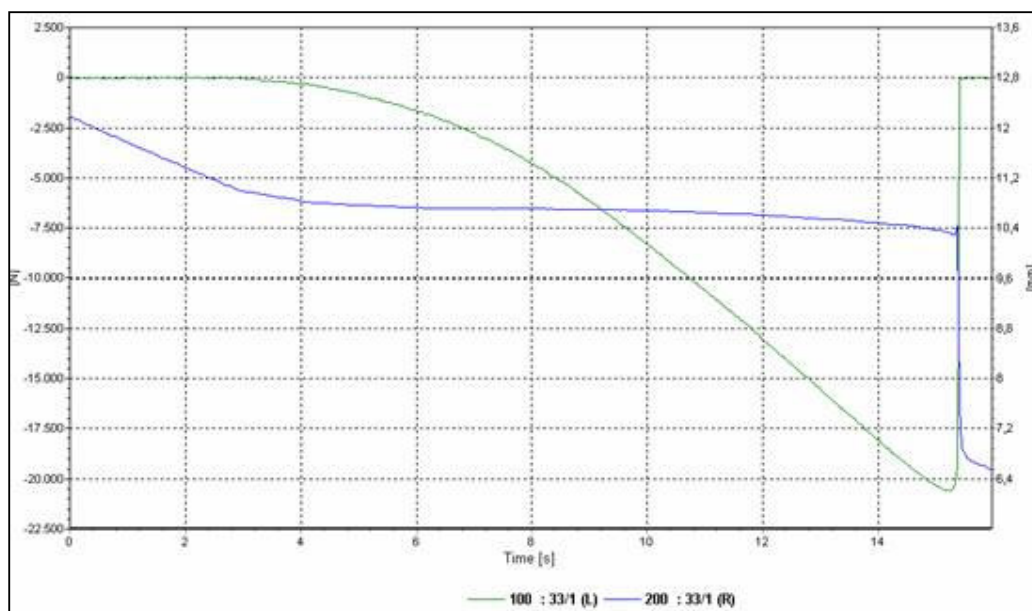


Figure E-2.20 Event 20: 25% Polyester 75% Unused Sand

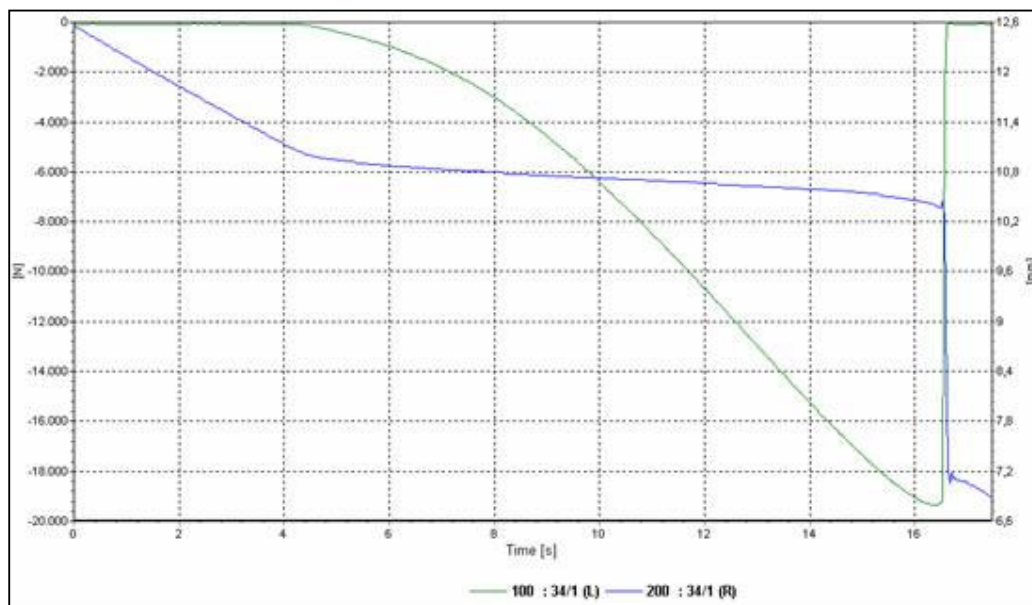


Figure E-2.21 Event 21: 25% Polyester 75% Unused Sand

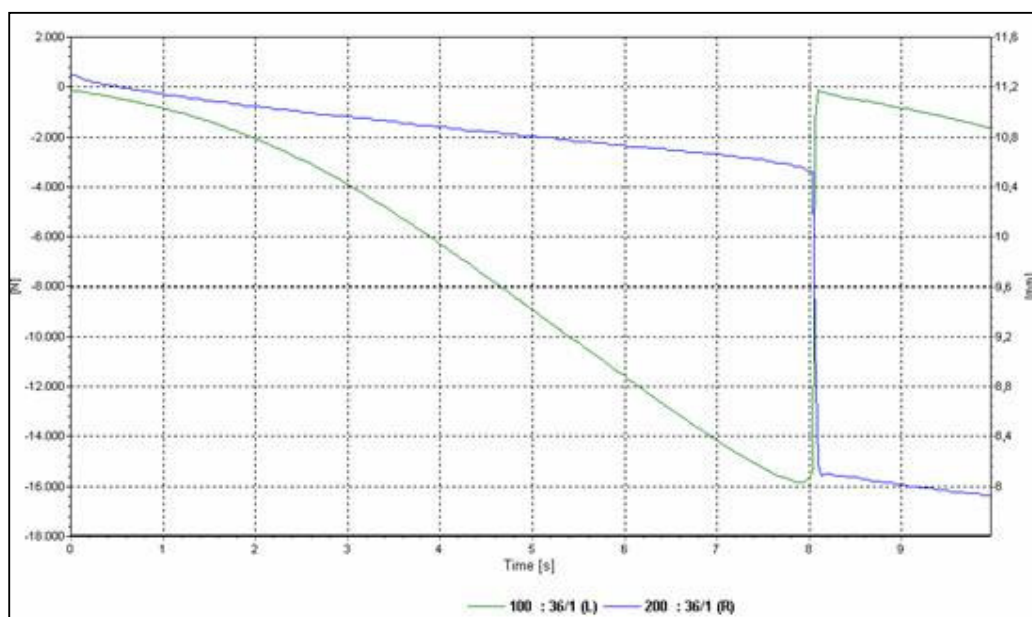


Figure E-2.22 Event 22: 25% Polyester 75% Unused Sand

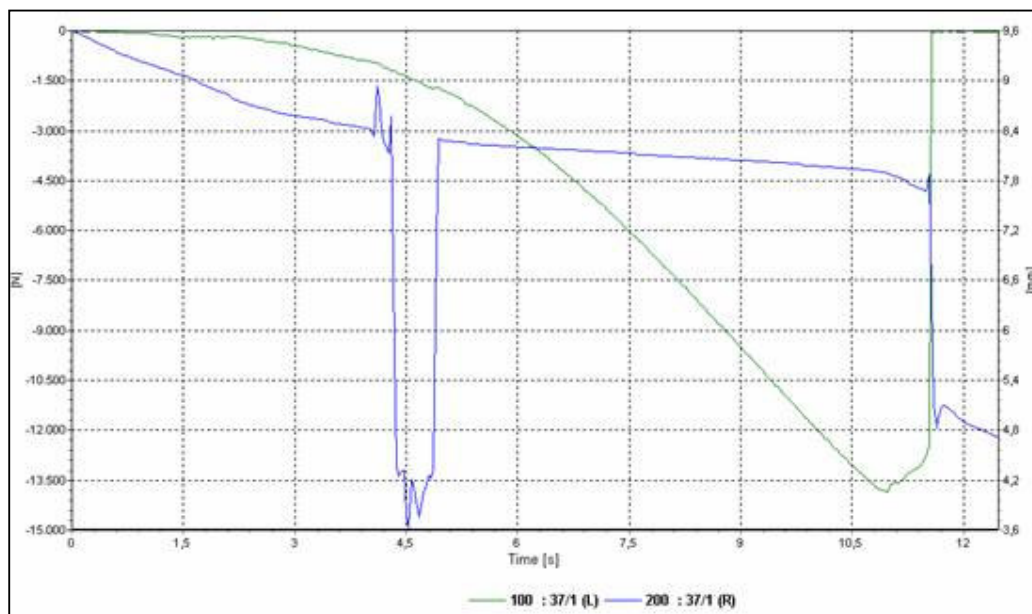


Figure E-2.23 Event 23: 25% Polyester 75% Unused Sand

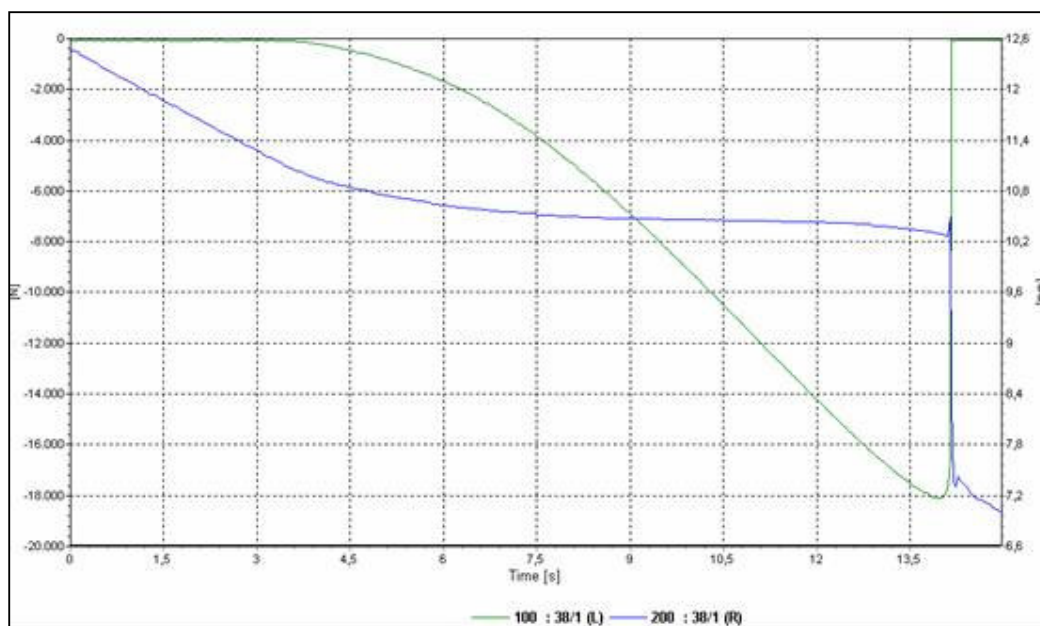


Figure E-2.24 Event 24: 30% Polyester 70% Unused Sand

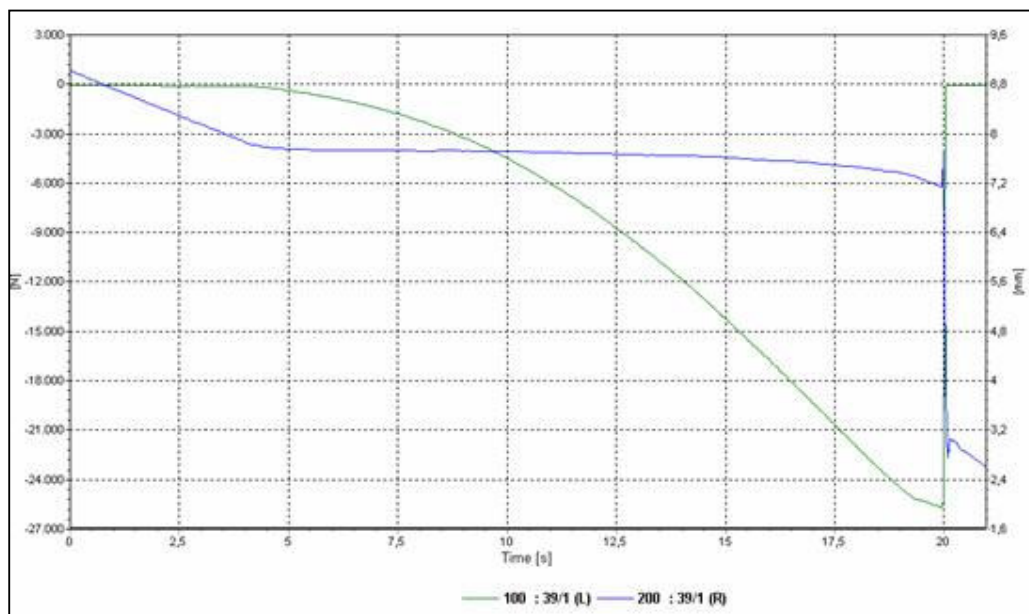


Figure E-2.25 Event 25: 30%Polyester 70% Unused Sand

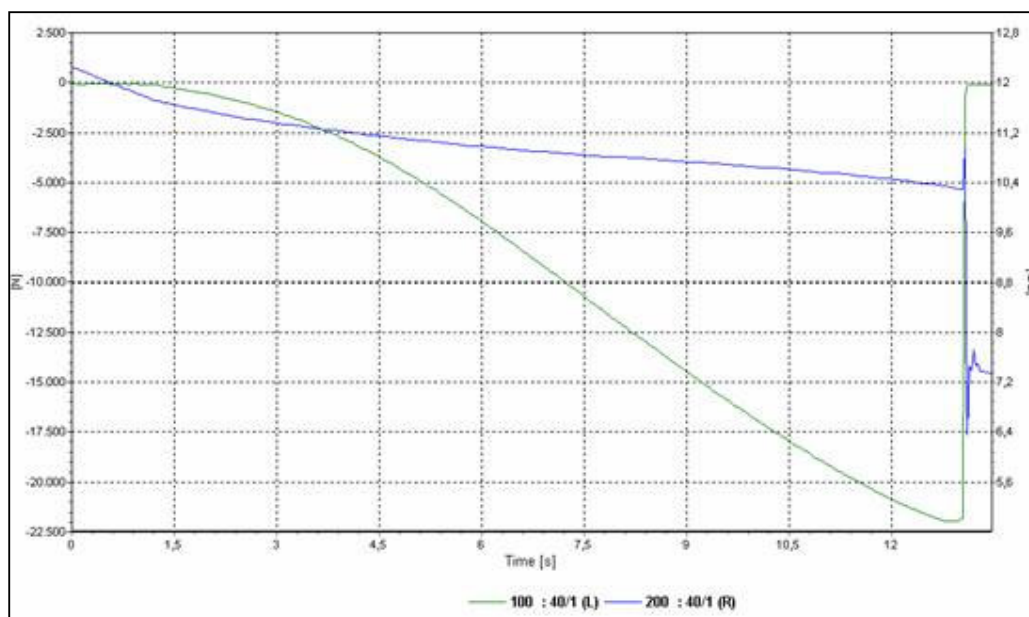


Figure E-2.26 Event 26: 30%Polyester 70% Unused Sand

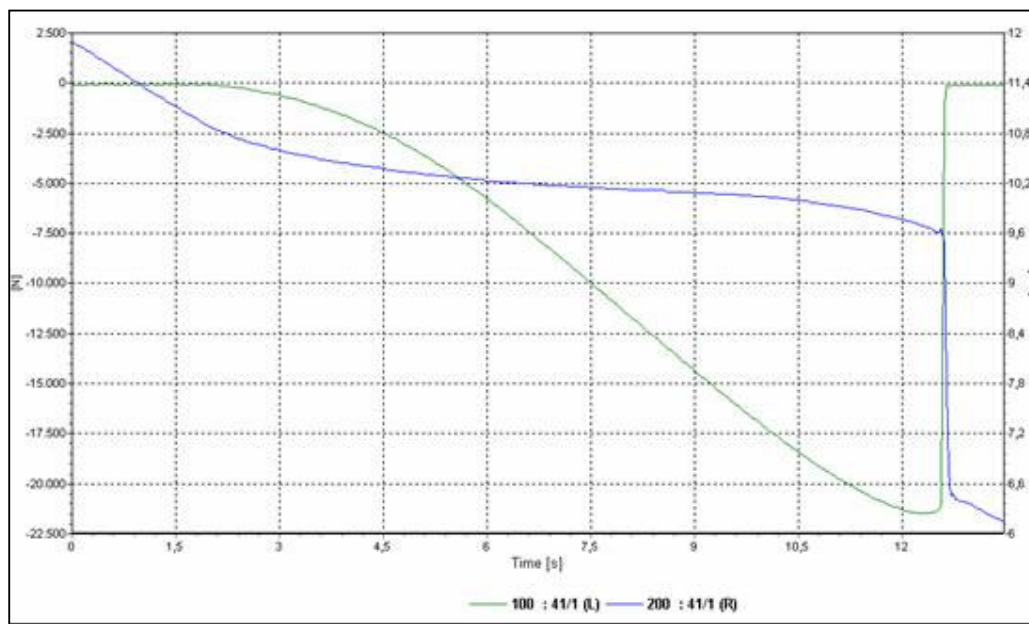


Figure E-2.27 Event 27: 30%Polyester 70% Unused Sand

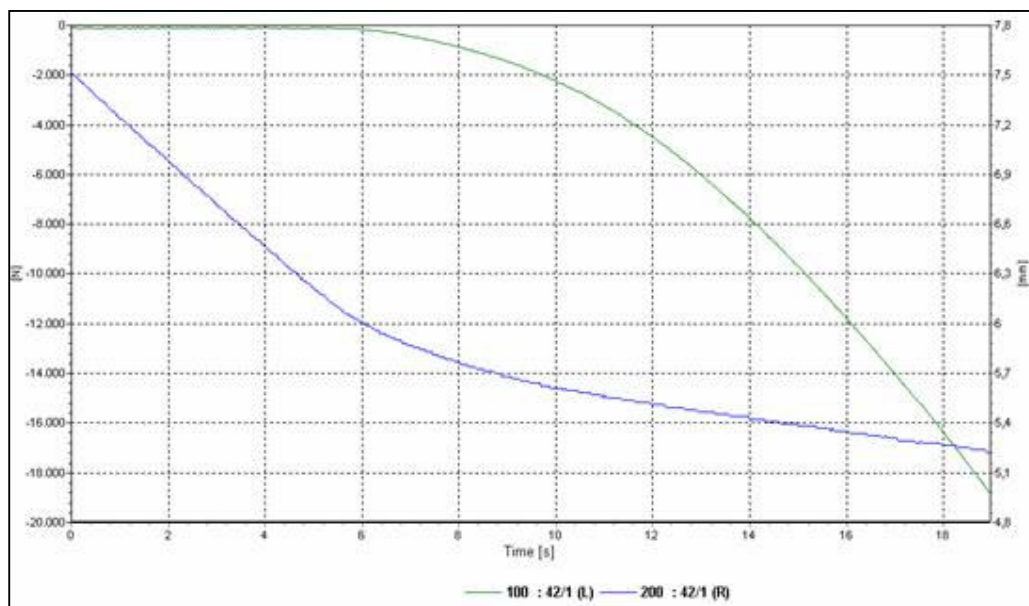


Figure E-2.28 Event 28: 20% Polyester 80% BaSO₄

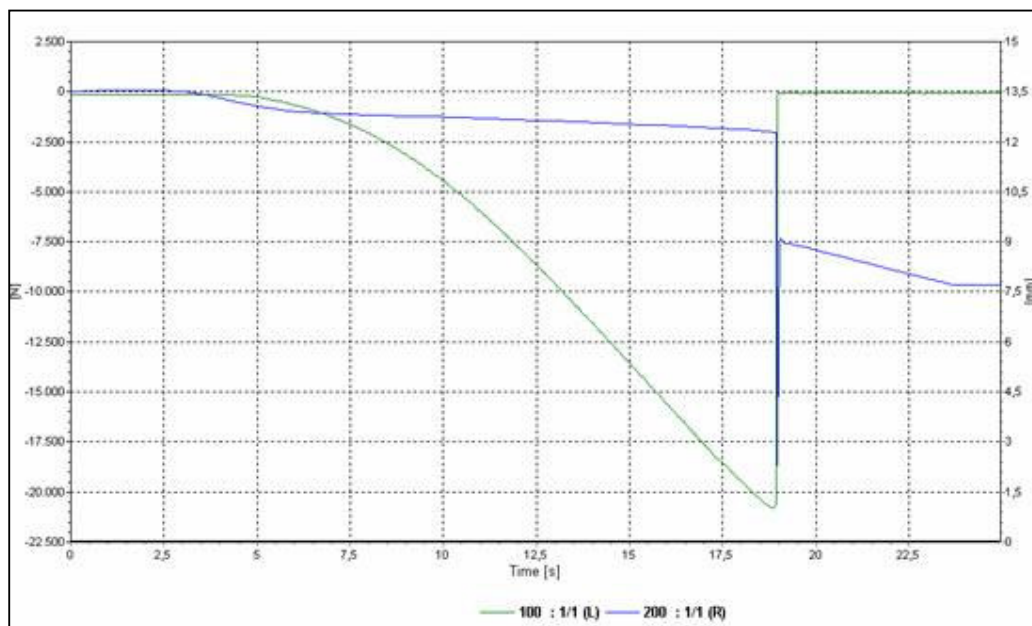


Figure E-2.29 Event 29: 20% Polyester 80% BaSO₄

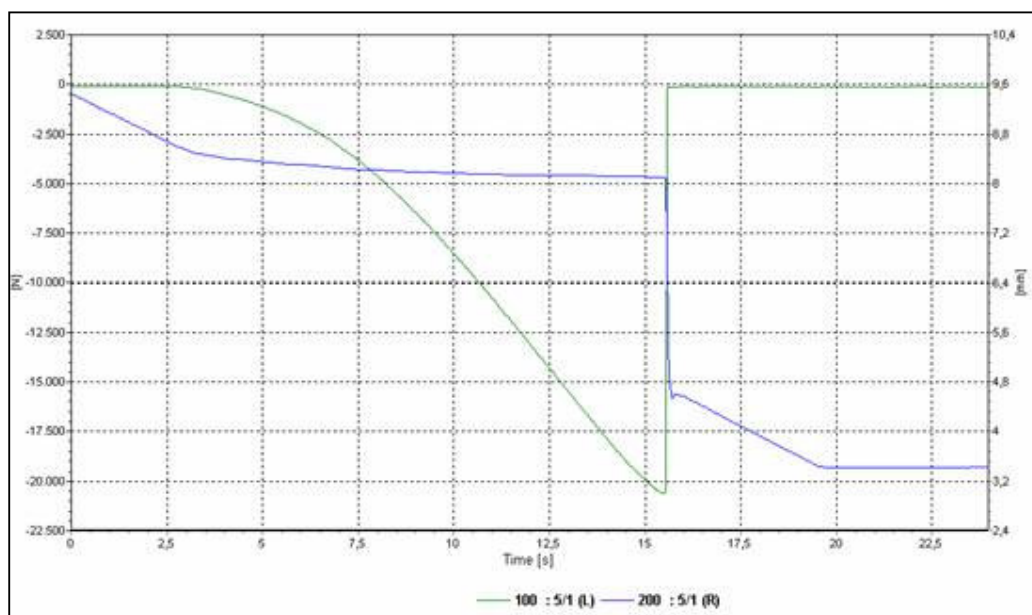


Figure E-2.30 Event 30: 20% Polyester 80% BaSO₄

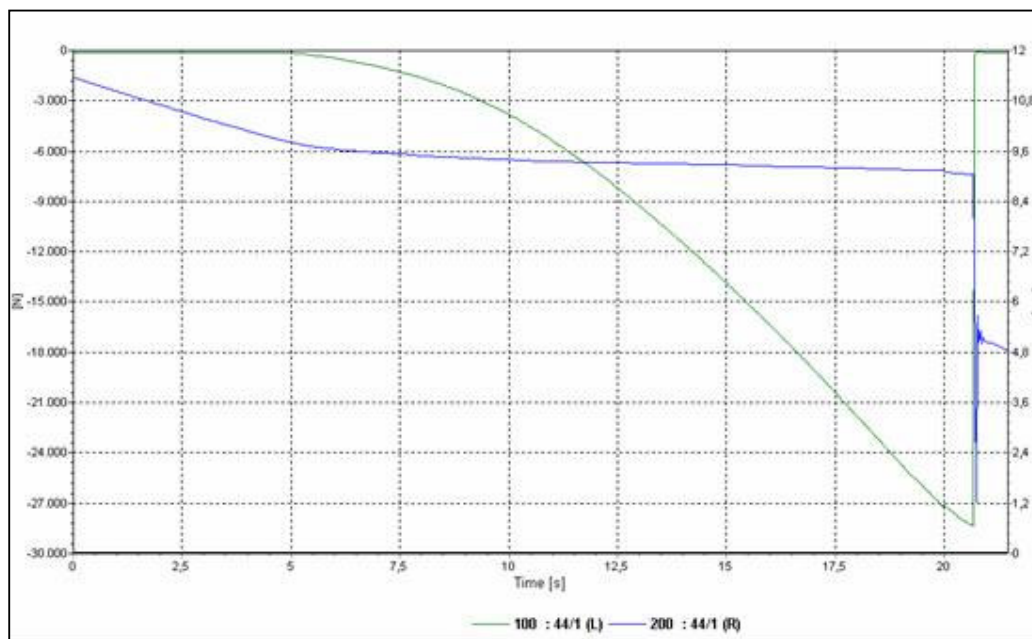


Figure E-2.31 Event 31: 25% Polyester 75% BaSO₄

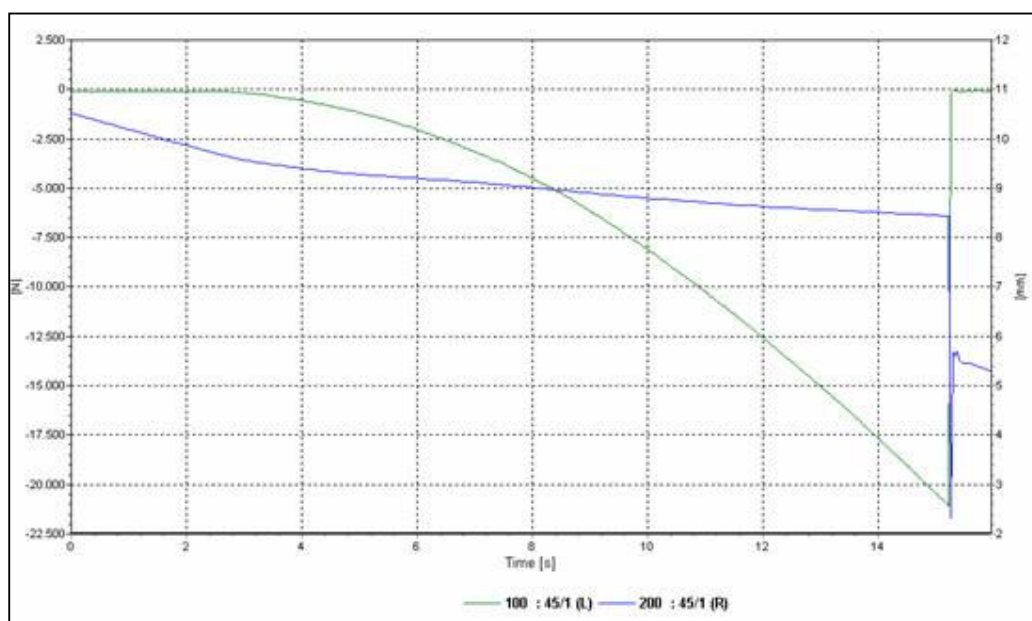


Figure E-2.32 Event 32: 25% Polyester 75% BaSO₄

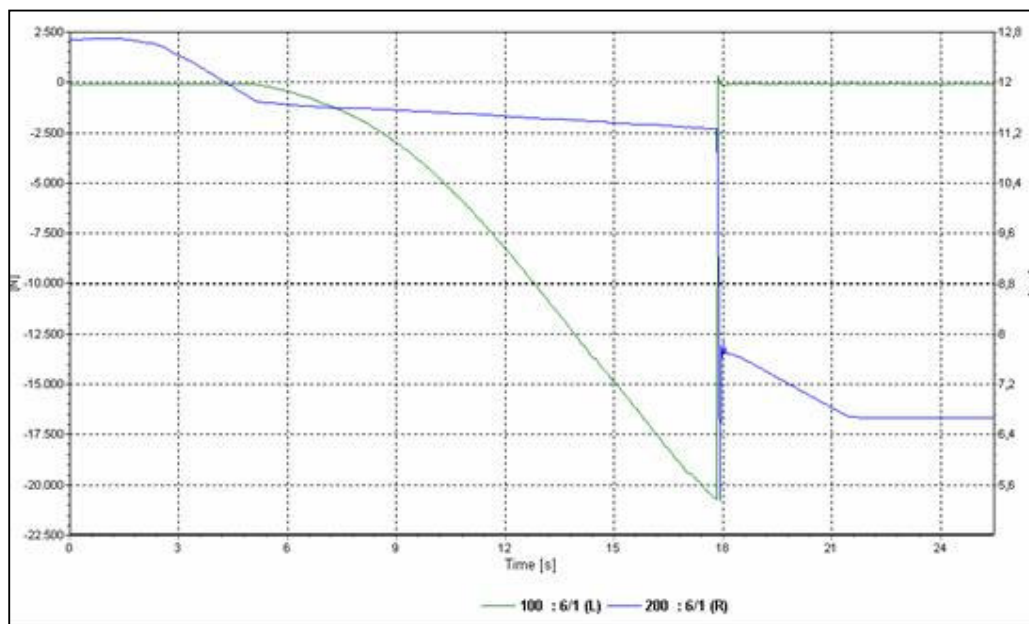


Figure E-2.33 Event 33: 25% Polyester 75% BaSO₄

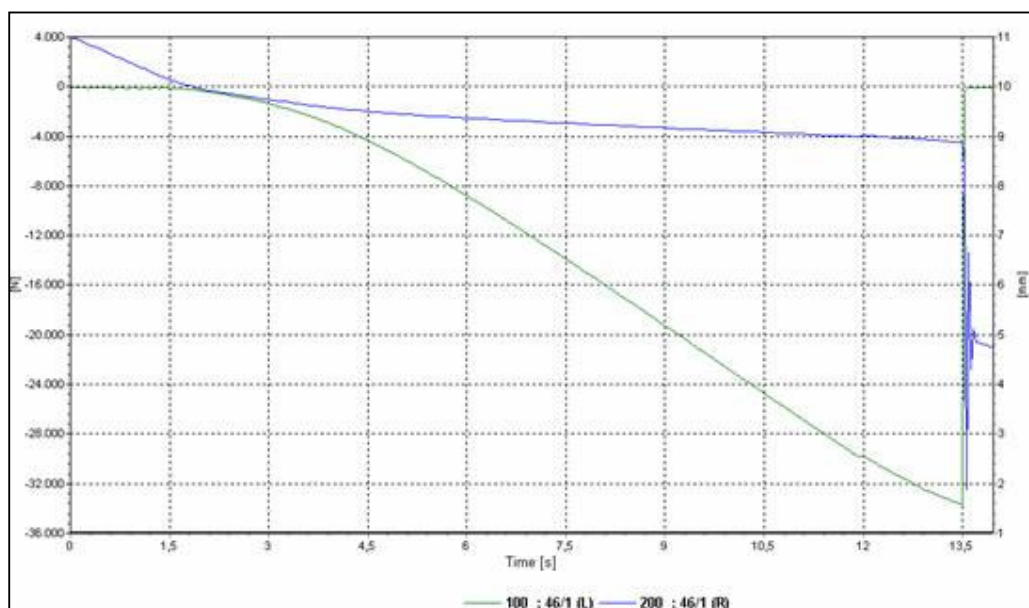


Figure E-2.34 Event 34: 30% Polyester 70% BaSO₄

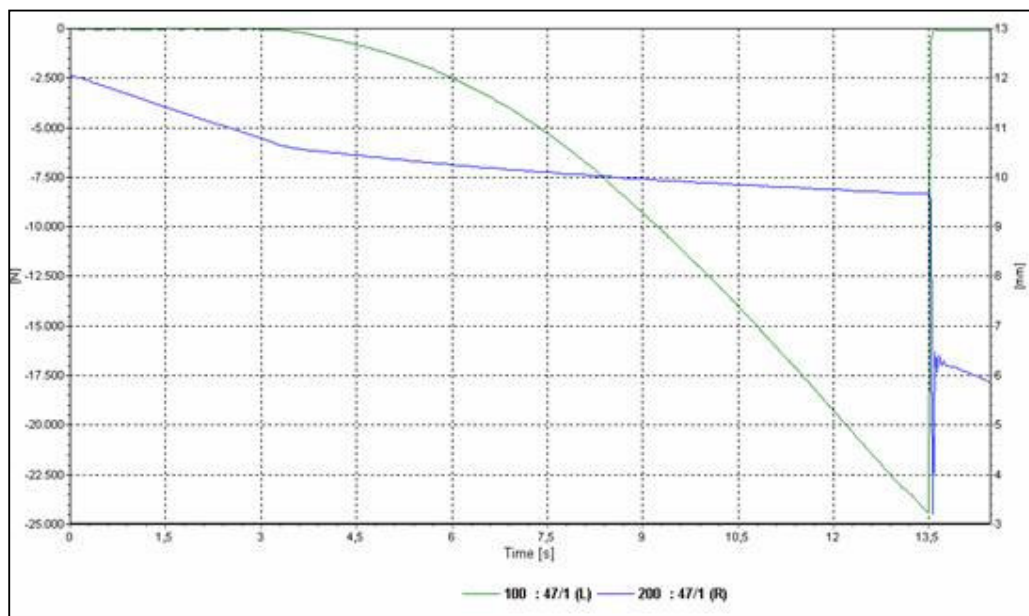


Figure E-2.35 Event 35: 30% Polyester 70% BaSO₄

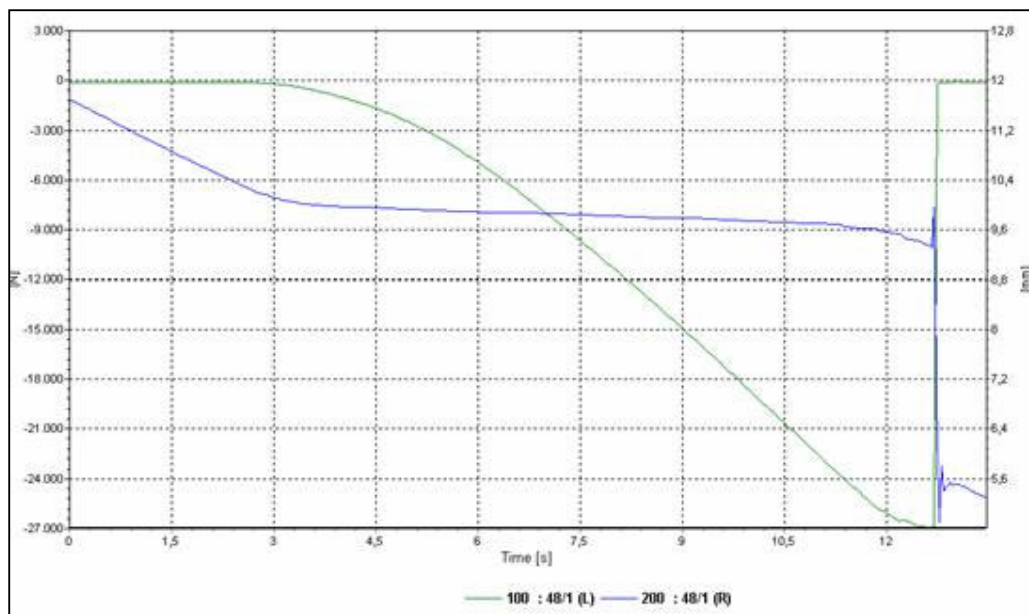


Figure E-2.36 Event 36: 30% Polyester 70% BaSO₄

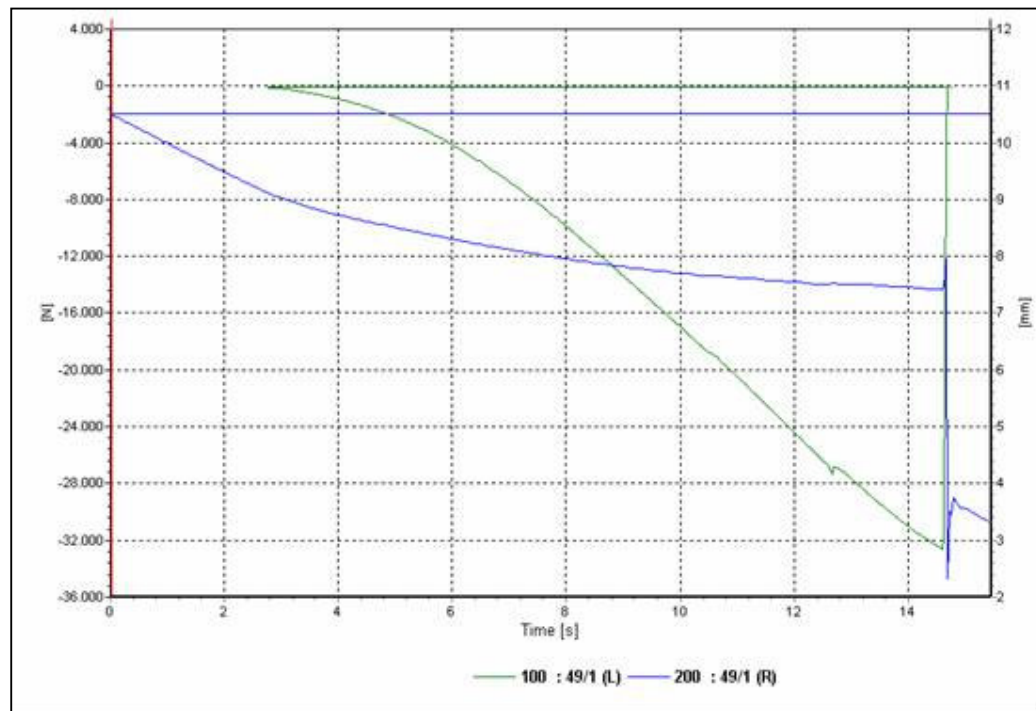


Figure E-2.37 Event 37: 30% Polyester 70% BaSO₄

BIOGRAPHY

Didem Tüysüz was born in Ankara in 1982. She was graduated from Kabataş High School in 2000. She admitted to Istanbul Technical University, Mechanical Engineering Department and graduated as a mechanical engineer in 2004.

She was registered as M.Sc. Student to Design and Manufacturing Programme of the Institute of Science and Technology of Istanbul Technical University in 2004.

She started to work in ARCELİK Washing Machine Production Plant as production engineer in 2004.

She maintained her thesis in ARCELİK Research and Technology Development Center, Material Technologies Department.